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FACTORS INFLUENCING THRESHOLDS FOR MONOCULAR MOVEMENT PARALLAX

BY C. H. GRAHAM, KATHERINE E. BAKER, MARESSA HECHT, AND V. V. LLOYD

From the Psychological Laboratories of Columbia University

INTRODUCTION

When an observer views monocularly a visual field containing objects at different distances, movements of the observer's eyes with respect to the visual field or movements of the visual field with respect to the observer's eyes cause a differential angular velocity to exist between a line of sight to a fixated object in the field and a line of sight to some other object. The condition of differential angular velocity holds for binocular vision as well as monocular. Objects farther away than the fixated object appear to move more slowly than the fixated object and, if the observer is moving, the farther objects appear to move in the same direction as the observer. Objects nearer than the fixated object appear to move faster than the fixated object and in the opposite direction. The greater the distance between objects the greater the difference in apparent speed. This phenomenon is called monocular movement parallax and provides an important cue for monocular space perception.

The importance of the cue has long been recognized, but we are still in ignorance of its quantitative implications. Helmholtz (4) described the effect in some detail, but presented no experimental data. Bourdon (1) in an experiment in 1898 observed that the relative positions of two illuminated points could be perceived more accurately when the head was moved. In this investigation, two illuminated points of equal visual angle were placed one above the other at different distances. When the *S* was allowed to move his head at will, it was found that a point six meters away could just be distinguished as farther away than one at five meters. Bourdon also observed that judgments were made more easily when the farther point

was above the nearer and when they were separated by a visual angle of 1° as compared with 6°. Neither extent nor speed of head movement was controlled in the experiment, and it is certain that other conditions result in much finer discriminations than are reported by Bourdon.

Tschermak (**6**) has studied the relative accuracy of monocular movement parallax and stereoscopic parallax in a situation presenting vertical and horizontal wires in frames set at different distances. Conditions were such that the *S* moved his head at will, but always in a plane normal to the direction of the wires. Horizontal head movement seems to be more effective than vertical movement. Tschermak's experiment has the deficiencies of Bourdon's; in addition, viewing distances for the two conditions of movement axis varied. No theoretical treatment of the phenomenon is given.

It is the purpose of the present experiment to make a preliminary investigation of monocular movement parallax. In particular, we are interested in observing the influence on a basic datum, threshold differential angular velocity, of such factors as differential size of comparison stimuli, intensity of illumination, rate of movement of objects and axis of movement.

Stimulus Specification

Monocular perception of movement parallax occurs when an observer moves with respect to observed objects or observed objects move with

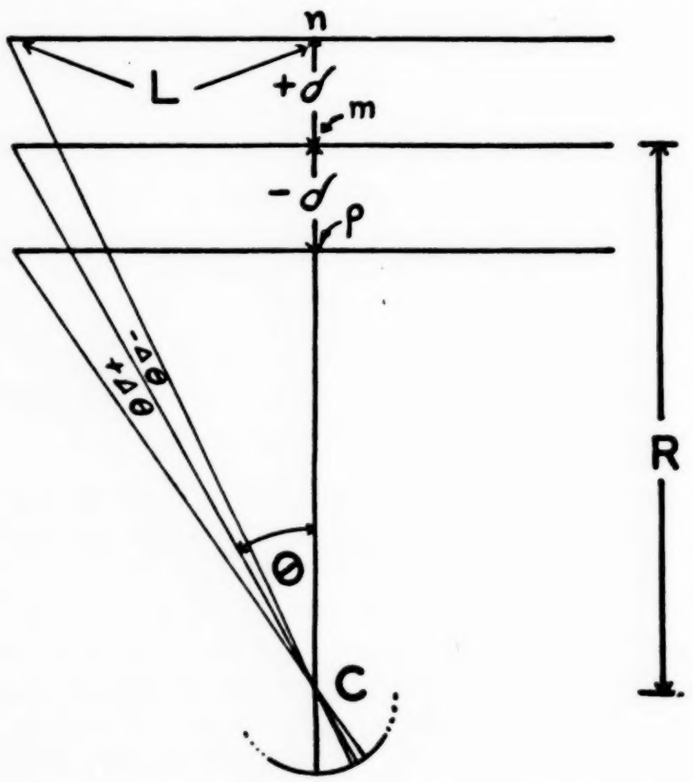

Fig. 1. Geometric diagram of monocular movement parallax existing when the subject is stationary and objects are moving. For explanation see text.

respect to the observer. For experimental purposes, it is convenient to use a situation in which the S remains stationary while the objects move. [For an analysis which applies to other situations as well, see Graham (2).]

Fig. 1 shows a geometrical diagram of the situation existing when the observer is stationary and the objects move. Since the case of objects moving at a constant rate is of greatest interest to the psychologist, we shall restrict ourselves to that treatment.

We represent by m the position of an object at a distance R from the center of rotation, C, of the single observing eye. The symbol p represents the position of another object at a distance $R - \delta$ from the center of rotation and n, that of an object at a distance $R + \delta$. All three positions are on a single line of sight.

Suppose that all three objects move at equal constant rates along a line parallel to the line joining the centers of rotation of the two eyes. After a given time, all of the objects will have moved through distance L. Movement through L results in angular displacements of θ for the object moving from m; $\theta + \Delta\theta$ for the object moving from p; and $\theta - \Delta\theta$ for the object moving from n. We are interested in knowing the differential angular velocity, $d(\Delta\theta)/dt$, which exists between the line of sight to the object moving from m and the line of sight to the object moving from n or p.

In radian measure and for angles which are not too large:

$$\theta = \frac{L}{R}. \tag{1}$$

On differentiation,

$$\frac{d\theta}{dR} = -\frac{L}{R^2},$$

or

$$d\theta = -\frac{L\,dR}{R^2}. \tag{2}$$

When δ (Fig. 1) is small in comparison with R, it may be taken equal to dR, and $d\theta$ may be considered equivalent to $\Delta\theta$. On substituting these terms in equation (3), we obtain the expression:

$$\Delta\theta = -\frac{\delta L}{R^2}, \tag{3}$$

which gives the relations existing among the variables $\Delta\theta$, δ, L, and R of Fig. 1. The sign of $\Delta\theta$ depends upon the signs of δ and L. Since $\theta = L/R$, equation (3) becomes

$$\Delta\theta = -\frac{\delta}{R}\cdot\theta, \tag{4}$$

the sign of $\Delta\theta$ being determined by the signs of θ and δ. On differentiation, expression (4) becomes

$$\frac{d(\Delta\theta)}{dt} = -\frac{d\left[\frac{\delta\cdot\theta}{R}\right]}{dt}; \tag{5}$$

and since R and δ are independent of θ, the final expression becomes

$$\frac{d(\Delta\theta)}{dt} = -\frac{\delta}{R}\cdot\frac{d\theta}{dt}. \tag{6}$$

On the basis of equation (6) it is possible to calculate the differential angular velocity existing between two objects when the following terms are known: (a) the distance to one object, (b) the distance (which must not be too large) between objects, and (c) the rate of movement characteristic of both objects.

For the case of constant rate, which is of most interest to us,

$$\omega = \frac{\Delta\theta}{t} = -\frac{\delta}{R}\cdot\frac{\theta}{t}, \tag{7}$$

and for threshold,

$$\omega_t = -\frac{\delta_t}{R}\cdot\frac{\theta}{t}, \tag{8}$$

where ω_t and δ_t are threshold values of ω and δ. If ω_t is measured in seconds of arc per second, equation (8) becomes

$$\omega_t = -206{,}000\,\frac{\delta_t}{R}\cdot\frac{\theta}{t}. \tag{9}$$

Our apparatus has been designed to provide data from which differential angular velocity may be calculated by equation (9). The differential angular velocity existing when δ_t represents the threshold distance between two objects for the conditions of perceptible movement parallax is called ω_t, as in equation (9), and will be referred to as such in the text.

Apparatus

The apparatus provides a means of presenting to one eye of the *S* a rectangular field containing two needles, one stationary and the other movable, seen as opaque against the field illumination and in a plane parallel to the principal line of sight through the apparatus. The movable needle may be displaced toward or away from the *S*. The mechanism holding the needles may be moved at a constant speed in a plane perpendicular to the principal line of sight, thus producing monocular movement parallax when the two needles are not at equal distances from the *S*'s eye. The task presented to the *S* is to set the movable needle in such a way that both needles appear to be in the same plane or so that no movement parallax is perceptible.

Fig. 2 is a diagram of the apparatus, with the various parts separated by more than the proper scale for the sake of clarity. The broken line passing through all parts represents the principal line of sight. The *S* places his eye (E) directly in front of an artificial pupil (of three mm. diameter) and looks through a metal tube (T) (1.25 in. diameter), the inside of which has been blackened to reduce reflections. The end of the tube is fitted into a wooden filter box (F) where Wratten neutral tint filters may be placed for intensity control. The front of the filter box holds a four-diopter double convex lens (L) to provide nearly parallel rays from the stimulus; thus accommodation is always for infinity.

Placed between the filter box and the rest of the apparatus is a black metal shield (S) which allows the *S* to view only that part of the equipment which is visible through the rectangular aperture (A) ($1\frac{1}{8} \times 1\frac{1}{2}$ in.). (Early in the experiment 'scalloping' was provided for the two sides of the aperture in order to eliminate the possibility that a straight reference line at either end of the excursion might serve as a cue for 'lining up' the needles.) The mechanism holding the needles and for moving them is directly behind the shield. A metal frame (FR) is fastened

in an upright position on a metal platform (P), the platform being supported in front by a metal rod which slides in two pillow blocks, and behind by a small metal wheel which rolls along a metal runway (R). A metal block is fastened to the top of the frame by means of a set screw. The block holds the stationary needle (SN) at a distance of 9.5 in. (9.75 in. in some of the early experiments) from the lens in the front of the filter box. The needle has a diameter of 0.025 in. and subtends a visual angle of 9 min.

Directly below the stationary needle and separated from it by 0.008 in. is a movable needle (MN), of diameter equal to that of the stationary needle. This needle is set into a square rod which slides over the bottom of the frame. The square rod fits into square holes in two metal blocks also fastened to the platform. The movement of the rods through the holes is a smooth one in a plane parallel to the principal line of sight. A ball soldered to one end of the square rod is made to bear firmly by means of a spring against a micrometer. Movements of the micrometer, held in place by a pillow block, cause the movable needle to be displaced toward or farther

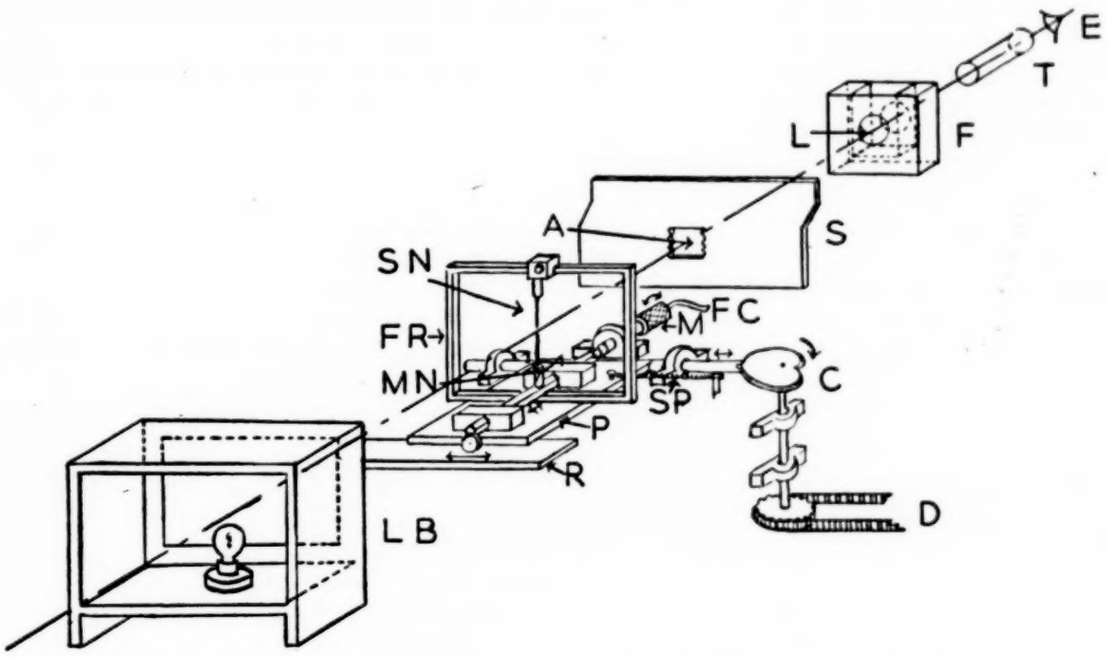

FIG. 2. Isometric diagram of the apparatus used to measure the precision of monocular movement parallax settings. The parts have been separated for the sake of clarity. Explanation in text.

away from the *S* by measurable amounts, determinable to a thousandth of an inch. The subject manipulates the micrometer by turning a knob, movements of which are transmitted to a flexible cable (FC) by means of two gears and a chain belt; the flexible cable is connected with the micrometer.

The platform holding both stimulus needles moves laterally. One end of the cylindrical rod supporting the platform is held against a cardioid cam (C) by means of a steel tension spring (SP). A roller is set into a slot in the end of the rod to reduce friction between the rod and cam. The cardioid cam was carefully constructed to give a total excursion of the needles of about two inches at a *constant* speed except at either end of the excursion where the direction is changing. Only the linear part of the excursion is visible through the aperture (A) throughout the entire experiment. The cam is mounted on a shaft turned by a chain drive (D) from a 1/15 h.p. motor running on 110 volts D.C. Interposed between the motor and the drive mechanism is a series of pulley wheels, choice of any one of which allows for one of four different speeds of movement of the cam, and, consequently, of the stimulus needles. The speeds of movement of the stimulus needles have been calibrated by means of kymographic records of the slowest movement, the other speeds being calculated from the ratio of the time per cycle at each speed to the time per cycle at the slowest speed. To the *S*, the needles appeared to make an oscillatory movement back and forth across the field. At either end of the excursion, the needles disappeared behind the shield for a moment as the direction of motion changed.

Illumination of the stimulus field is provided by a light box (LB) placed directly behind the platform holding the stimulus needles. The box is faced with an opal glass screen ($6\frac{1}{2} \times 4$ in.) lighted from behind by a tungsten bulb run on direct current. The diffusely illuminated surface provided 100 millilamberts, as measured by a Macbeth illuminometer, when the lamp voltage was adjusted to 7.5 volts.

The *S* sat inside a light-tight cubicle. The metal tube and the knob for manipulating the micrometer were inside the cubicle, while the rest of the apparatus was placed outside. Thus the *E* could read the micrometer and make all necessary adjustments of the apparatus without interfering with the *S*.

Procedure

The general procedure used in these experiments was to obtain a variability measure, the standard deviation of 'equality' settings for the movable needle, as a measure of δ_t. The variability measure ($\delta_t = SD$) was used in the calculation of the differential angular velocity, ω_t, existing between the movement of the two needles at threshold.

The *S* sat in the dark room and was allowed to dark-adapt for a period the length of which was dependent on the particular problem being investigated. Following dark adaptation, the *S* was instructed to look through the viewing tube and to turn the knob connected to the micrometer so as to set the movable needle in such a position that it appeared to be at a distance equal to the distance of the stationary needle or so that no movement parallax was perceptible. Two types of judgment were encountered in the experiments; some *S*s were unable to discriminate the effect of parallax as a spatial difference, while others reported that they could and did. This problem will be discussed in a later section.

The *S* fixated and followed the needles with his eye, thus maintaining foveal fixation. Table I is a summary of the results of a control experiment on the effects of fixation conditions

TABLE I

Effect of Fixation

Standard deviations of settings (δ_t) are presented for two fixation conditions: fixation on the moving needles and fixation when the eye regards a stationary point in the center of the field. Two sessions under the former condition. Needle diameter = 0.025 in. Data in inches.

Subject	Fixation on Moving Needles	Fixation on Spot: I	Fixation on Spot: II
RZ	0.011	0.028	0.055
HB	.009	.022	.056
WA	.015	.055	.059
AR	.017	.082	.078

made with four *S*s at a brightness of 100 millilamberts and a needle movement of about seven degrees per second. The table shows that the threshold, indicated by the standard deviation, is two to five times higher with constant fixation in the center of the visual field than when the eye was allowed to follow the needles. A second session under constant fixation conditions did not show an improvement in the thresholds and, therefore, it was concluded that the differences obtained in the first session were not due to the greater practice of the *S*s under 'following' conditions.

The *S* made 20 settings for each experimental condition, the *E* displacing the movable needle between settings. Since it was found possible to influence the average of settings by the direction and extent of displacement of the movable needle by the *E*, care was taken to set the needle at various distances from the true equation point and on both sides of it. For each 20 settings the mean and the standard deviation of setting were calculated.

A preliminary experiment showed that the standard deviation obtained from 20 settings was the same as one obtained from a larger sampling of settings. Each of two *S*s made 75 settings in each of two experimental sessions. Illumination was 100 millilamberts and the needle movement occurred at the relatively slow speed of about seven degrees per second. The standard deviation was calculated for the first 10 settings, for the first 15, 20, and so on in steps of five

up to the full 75 readings. In both sessions with each *S* it was found that the *SD* obtained from the first 20 settings did not vary from the average of the 14 *SD*'s obtained in each session by more than one standard deviation about the mean *SD*. Therefore, we have adopted the practice of considering the *SD* of 20 settings as a stable measure of threshold.

Prior to each experimental session several calibration checks were made. The speed of movement of the needles was calculated from the average time per cycle of the cardioid cam. Three measurements with a stopwatch were made of the time required for 10 cycles, the average of the three measurements divided by 10 being taken as the time per cycle. The 'true' equation point for the needles was found for each day's readings for each *S* from the average of 10 coincidence acuity settings made by the *E* through a viewing tube with artificial pupil (three mm. diameter) permanently set up in such a way that the *E*'s line of sight through the stationary needle and the center of the artificial pupil was perpendicular to the *S*'s principal line of sight through the apparatus. The acuity settings were made from a distance of about eight in. against an illuminated background of 100 millilamberts.

Considerable care was taken that the two needles should both lie on a single line of sight when placed in the middle of the visual field. This was accomplished by the *E*, who looked through another tube which could be swung into place in the position of the light source. The *E* sighted through the exit pupil of the tube and lined up the center of the lens and the center of the aperture in the shield. After this procedure was accomplished, *E* set the movable platform so that the lower needle, set for 'equation,' coincided with the center of the aperture, as marked on the back of the shield. Then the upper needle was adjusted so that it was directly above the lower needle within the limits of coincidence acuity of the *E*. This adjustment was checked by the *S* who looked through his tube, and if *S* and *E* did not agree, further adjustments were made until agreement was reached. In addition to the check mentioned above, the *S* was asked to report if the lower needle remained aligned with the upper stationary needle as the movable needle was moved nearer and farther from him, the platform being held stationary.

A total of 10 *S*s was used in all experiments.[1] All *S*s had normal vision or vision corrected to normal. No *S* had any outstanding astigmatic defects that could be shown from a preliminary examination with a standard clinical chart. Of the 10 *S*s, five (CG, HB, MS, JA, and CM) reported that they could clearly discriminate the spatial characteristics of the movement, while the rest (RZ, AR, WA, SV, and VL) reported that they made their settings on the basis of coincidence acuity and the recognition of the difference in speed of the two needles as they moved across the field.

Experimental Investigations

Differences in Diameter of Needles

Objects of the same dimensions placed at different distances from the eye subtend different visual angles. This difference in visual angle is a cue to space perception and is unavoidable in our experimental situation where the movable needle must be placed at different distances from the *S*'s eye during the course of a setting. In order to test the influence of differences in visual angle subtended by the needles, we have observed the effect of three different sizes of stationary needle on the determination of thresholds. If a setting is made or greatly influenced by differences in the visual angles subtended by the stimuli, we should expect the mean of settings for equality to be displaced toward the position where the standard and variable needle subtend equal visual angles.

Fig. 3 shows the results of a test made with three *S*s (AR, RZ, and WA) at an illumination of 100 millilamberts and with needles moving at a rate

[1] We are indebted to the following *S*s for results obtained in many hours of tedious experimentation: Misses Anne M. Ritter, Wilma E. Artus, Susan Vitan, Carmen Miller; Mrs. Marguerite R. Smith; Messrs. Joseph J. Antonitis, Howard D. Baker; and Rev. Richard T. Zegers, S.J. We also wish to thank Mr. Baker for his considerable help in the construction and design of several parts of the equipment.

of seven degrees per sec. A theoretical curve has been drawn showing the average setting that would be predicted had the judgments been made on the basis of equality of visual angle. The obtained curve is a straight line with a slope of zero and does not conform to the predictions made when visual angle is considered the cue for the judgments. The actual data, presented in Table II, show no tendency for the mean of settings to vary with the size of the stationary needle. Precision of settings, in terms of δ_t, is only slightly poorer for needles of unequal size.

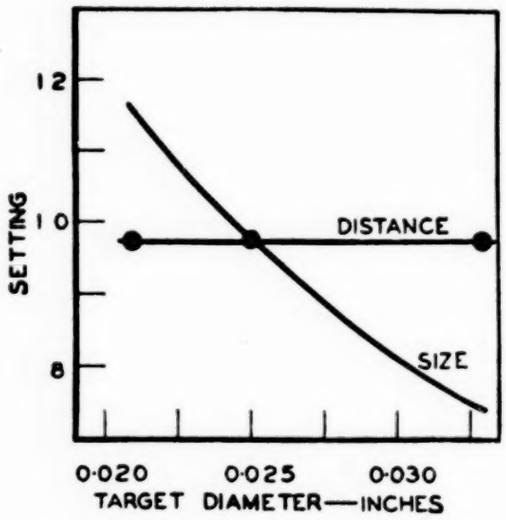

FIG. 3. Distance of setting of the movable needle as a function of the diameter of the stationary needle. The stationary needle was at a distance of 9.75 inches from the eye. The curved line represents the theoretically expected curve for settings made on the basis of visual angle. The horizontal line is the experimentally obtained curve for judgments made on the basis of distance of the stationary needle.

TABLE II

EFFECT OF SIZE OF NEEDLES

Average distances of setting for movable needle (diameter = 0.025 inch) are presented for three diameters of stationary needle; also the δ_t values (in inches). The stationary needle was at a distance of 9.75 inches. The distances at which the movable needle subtends a visual angle equal to that of the stationary needle are given in the last column. Rate of needle movement = 7 degrees per second. Brightness = 100 millilamberts. ω_t may be calculated from δ_t values by equation (9). Data are averages for three subjects (RZ, WA and AR).

Diameter of Needle in Inches	Average Distance of Setting in Inches	Average Precision of Setting	Distance for Visual Angle Equal to Stationary Needle
0.021	9.76	0.025	11.61
.025	9.76	.015	9.75
.033	9.76	.021	7.39

Intensity of Illumination

It has been repeatedly observed that many visual phenomena; e.g., intensity discrimination and visual acuity (Hecht, **3**; Shlaer, **5**), vary systematically with changes in illumination, and it is of interest

to investigate the dependence of ω_t on this variable. Wratten neutral tint filters were used to control intensity. Each of four *Ss* (one tested twice) gave values (each based on a series of 20 settings) at 14 different intensities varying from log I equals -2.3 to log I equals 2.0. (Intensities are in millilamberts.)

The *Ss* were dark adapted for 10 min. before the determinations at the lowest intensity. This period of time is sufficient for cone vision.[2] After the initial period of dark adaptation, the *Ss* were light

TABLE III

EFFECT OF INTENSITY OF ILLUMINATION

Log ω_t values are presented for each of four *Ss* (one used twice) for each of 14 intensity levels. The average log ω_t appears in the last column. δ_t (in in.) may be calculated by equation (9). [For these conditions log $\omega_t - 3.441 = \log \delta_t$.] Rate of needle movement = 7 degrees per sec. Needle diameter = 0.025 in.

Log I	Log ω_t					
	VL	CG	WA (1)	WA (2)	JA	Average
−2.3	2.55	2.46	2.64	2.41	—	2.51
−2.0	2.45	2.60	2.55	2.48	2.22	2.46
−1.6	1.21	2.02	2.62	2.84	2.17	2.27
−1.3	2.02	2.00	2.57	2.39	1.97	2.19
−1.0	1.78	1.96	2.22	2.22	2.07	2.05
−0.6	1.76	1.62	2.14	1.82	1.76	1.72
−0.3	1.83	1.71	2.37	2.00	1.62	1.90
0.0	1.48	1.92	1.95	1.93	1.65	1.79
0.4	1.87	1.48	1.48	1.92	1.87	1.63
0.7	1.67	1.76	1.78	2.28	1.70	1.84
1.0	1.62	1.92	1.84	2.01	1.34	1.55
1.4	1.62	1.80	1.95	2.12	1.56	1.78
1.7	1.52	1.62	1.80	1.87	1.65	1.73
2.0	1.89	1.62	1.70	2.12	1.52	1.81

adapted for two min. to each new and higher intensity before readings were made. Increments in intensity were in steps of approximately 0.3 log unit. All *Ss* used the bracketing method of setting, and ω_t values were obtained for each intensity level for each *S*.

Table III presents the experimental data. Since it was found that threshold differential angular velocity was distributed normally on a logarithmic scale, average log ω_t values are given in the table. Fig. 4 represents the data graphically. Table III shows that there

[2] The following test demonstrated that the lowest level (log $I = -2.3$) involved cone vision primarily. The opal glass source of illumination was viewed through a red filter (Wratten No. 70) and, by means of neutral tint filters, the illumination was reduced until no color was observable. The brightness of the red light was calculated for the color threshold on the basis of data obtained from a heterochromatic match made at a high intensity. The value of white light for which the needles (not moving) were just imperceptible was also determined and compared with the value of the red light for color threshold. The values of the two, in millilamberts, were quite similar, the color threshold being at log $I = -2.4$, and needle imperceptibility occurring at log $I = -2.6$.

is considerable variability from *S* to *S* and considerable scatter for the same *S*s. Nevertheless, the curve drawn through the average data indicates that, in general, log ω_t decreases with an increase in log I. The rate of decrease is rapid at low intensities, but the curve approaches an asymptote of log ω_t equal to about 1.7 for intensities above 100 millilamberts. The total change in log ω_t is approximately 0.8 log unit over the range of intensities used. The horizontal part of the curve, to the left, is drawn on the assumption that a limiting ω_t is reached at intensities below about log $I = -1.75$. This threshold may correspond to the threshold given by chance adjustments in the absence of effective visual stimulation. It is probable that needles of larger diameters would show a lower intensity threshold, since they could be seen at lower illuminations. This question is worth study.

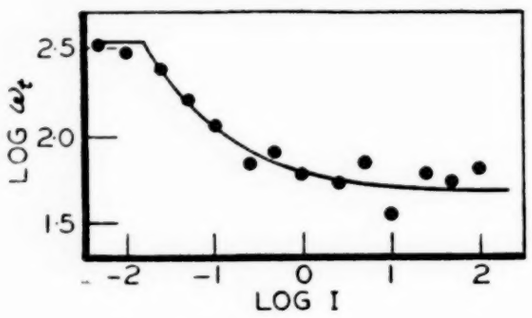

FIG. 4. Log differential angular velocity, ω_t, in seconds per second, as a function of log intensity level in millilamberts. Each point on the curve represents the average log ω_t for four subjects, one used twice.

It is interesting that two of the *S*s, CG and JA, reported that they used the parallax cue, while the others, WA and VL, used a coincidence cue. It is certain that the different modes of observation did not produce different types of result. All the data seem to fall along similar log ω_t vs. log I curves.

The curve fitted to the data as a first approximate description is Hecht's intensity discrimination curve (**3**):

$$\frac{\Delta I}{I} = c\left[1 + \frac{1}{(KI)^{\frac{1}{2}}}\right]^2, \qquad (10)$$

where c and K are constants; ΔI, the discriminable increment in intensity; and I, the adapting intensity. Log ω_t has been set equal to log $\Delta I/I$. This type of treatment implies that, in order to discriminate a threshold parallax, a threshold rate of separation ω_t is required, which, in a given small constant interval, dt, will allow a discriminable angular separation, $d(\Delta\theta)$, to appear between the lines of sight to the needles, each of which provides its diffraction pattern on the retina. A small difference, $d(\Delta\theta)$, is required before a differ-

ential diffraction pattern may be set up to signal the existence of monocular movement parallax. Thus, ω_t becomes a measure of difference in diffraction intensities and provides a ΔI seen against the general illumination, I. Further work, based on this analysis, must be carried out.

Rate of Movement

A. A series of experiments was concerned with the influence of rate of movement of the needles (hence, also the period of back and forth movement) on ω_t. By means of pulley wheel combinations and

TABLE IV

EFFECT OF RATE OF MOVEMENT

The standard deviation ($= \delta_t$) and $\log \omega_t$ (in sec. per sec.) for various rates of movement of the stimulus needles for each of the four *S*s used. Data for AR and RZ are averages for two sessions, while those for CG and HB are based on one experimental session. Brightness = 100 millilamberts. Needle diameter = 0.025 in.

Subject	Rate in Radians per second	δ_t in inches	Log ω_t sec. per sec.
AR	0.0946	0.0155	1.50
	.1213	.0145	1.58
	.1769	.0145	1.75
	.2400	.0200	2.02
	.3183	.0195	2.13
RZ	.1247	.0180	1.69
	.2011	.0195	1.93
	.2600	.0190	2.03
	.3259	.0170	2.08
CG	.0941	.0155	1.50
	.1279	.0148	1.62
	.1751	.0164	1.79
	.2803	.0160	1.99
	.3441	.0147	2.04
HB	.0891	.0098	1.28
	.1279	.0061	1.23
	.2079	.0059	1.43
	.2935	.0079	1.70
	.3564	.0051	1.60

the reduction of voltage across the motor, it was possible to obtain rates of movement of the needles ranging from 0.09 radian per sec. to 0.35 radian per sec. (The latter values, when multiplied by 57.3, give rates of movement in degrees per sec., 5.16 and 20.0, respectively.) Using five rates within this range we investigated the influence of rate with four *S*s. Two *S*s observed in four experimental sessions, at an illumination brightness of 100 millilamberts, each rate being presented twice; thus each ω_t value was based upon 40 settings. The different rates were presented once in ascending order and once in descending order. The other two *S*s made 20 settings at each

rate; one *S* made settings in an ascending order, the other, in descending order.

Table IV presents the data of the experiment. It presents (a) the rate at which the needles were moving in radians per sec., (b) the standard deviation of settings ($= \delta_t$), and (c) $\log \omega_t$ calculated from (a) and (b) in sec. of arc per sec. by equation (11). Each datum for *S*s AR and RZ is based on 40 settings, while each datum for CG and HB is based on 20.

Fig. 5 shows log threshold differential angular velocity in sec. of arc per sec. ($\log \omega_t$) as a function of rate of movement of the needles in radians per sec. The data for individual *S*s are shown separately,

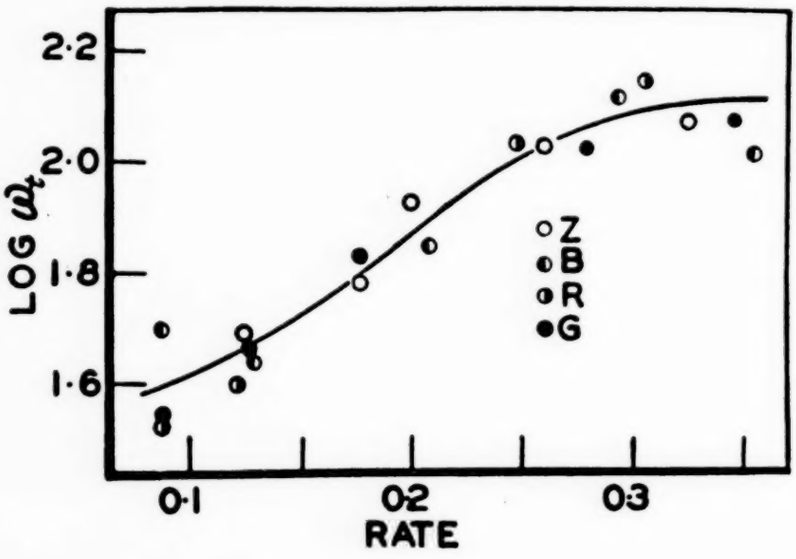

FIG. 5. Log ω_t as a function of rate of movement of the stimulus needles. Data for individual subjects are indicated by different symbols; the individual curves have been moved along the ordinate axis as follows: CG, raised 0.04 log unit; AR, raised 0.02 log unit; HB, raised 0.42 log unit.

each *S* being represented by a different symbol. Each individual curve has been raised or lowered an appropriate amount along the ordinate axis for the best agreement with the curve of subject RZ, and a composite curve has been drawn through all the data.

The curve in Fig. 5 shows that $\log \omega_t$ increases with increase in rate of movement of the stimulus needles. The curve is negatively accelerated and appears to be approaching an asymptote for rates greater than 0.35 radian per sec. A threefold change in rate is seen to result in a 0.5 log unit increase in $\log \omega_t$, which means that ω_t increases by a factor of about three. All *S*s showed the same relative amount of change in ω_t over the range of movements, although absolute values differed. It is necessary to point out that RZ and AR reported that they used needle coincidence as a cue for making their

settings. CG and HB used the parallax space cue. As shown in Fig. 5, different cues do not result in different shapes of curves.

B. With our apparatus, any change in rate of the stimulus needles is accompanied by a change (a) in the frequency with which they cross the visual field and (b) the duration of each exposure; that is, in general, the period of movement changes. Two control experiments were carried out to ascertain the influence of these factors on the relation between $\log \omega_t$ and rate of movement. One highly trained *S*, HB (who used the parallax cue), was employed in both experiments and only the extremes of the range of rates were tested. The level of illumination was the same as in the previous experiments (100 millilamberts).

In order to test the effect of frequency of exposure, the *S* was given one exposure of the stimulus field every 15 sec. and was required to report after each exposure whether or not the needles appeared to be in the same plane. Before each exposure the *E* set the movable needle at one of five positions in random order. [The needle settings covered two standard deviations (as obtained for subject HB in previous experiments) on either side of the objective equation point.] Twenty discriminations were made at each position. Between exposures a white cardboard was placed directly in front of the needles so that only one excursion from left to right was visible for any one exposure. The cardboard was illuminated by two auxiliary light bulbs which maintained the *S*'s level of adaptation between exposures at 100 millilamberts. Since the white cardboard was in nearly the same plane as the stimulus needles, accommodation was maintained at the distance of the needles throughout the experiments.

The integral distribution curve of positive responses for a rate of 0.098 radian per sec. yielded a δ_t ($= SD$) of 0.009 and a corresponding ω_t of 18.2. A δ_t of 0.012 was obtained for a rate of 0.32 radian per sec., making ω_t equal to 83.2. Thus, in this experiment the threshold ω_t increased by a factor of 4.5 for a threefold change in rate. This is to be contrasted with the earlier experiment of *A*, when a threefold change in rate resulted in about a threefold change in ω_t.

Duration of any given exposure is dependent upon the rate of movement and the width of the aperture through which the needles are viewed. By restricting the aperture to one-third of its original width it was possible to equate the duration of exposures for the fast and slow rates. Under conditions of the constant stimulus method used as above, subject HB made another 100 responses with the restricted visual field and the stimulus needles moving at 0.098 radian per sec. A δ_t value of 0.021 was obtained; this corresponds to a ω_t value of 42.7. This value is more than twice that obtained with the unrestricted field at the slow rate (18.2) and is 51 percent of the value of ω_t (83.2) found for equal durations of exposure but with the needles

moving three times faster. Thus with durations equal, threshold ω_t doubles with a threefold increase in rate. When both rate and duration vary, ω_t increases, at the higher speed, to 4.5 times its value at the low speed. It should be noted that restricting the field to one-third of its original size reduced the maximum momentary value of $\Delta\theta$ during an excursion to one-third. That is to say, for the slow speed and full field, the angular separation of the needles, $\Delta\theta$, at the end of the excursion is 39 min. from a coincidence alignment when one needle is 0.010 in. farther away from the eye than the other; but, when the length of excursion is reduced to one-third of its original value, the momentary angular separation, $\Delta\theta$, is only 13 min. at the ends of the excursion. The fact that δ_t was doubled with restriction of the excursion suggests that the limitations put on the use of a coincidence 'lining up' by such a restriction might be important.

Certainly, further experiments should be carried out on the analysis of the factors considered above. One would like to know, for example, whether the poorer thresholds at higher rates are due to imperfect following of the needles by the eye, or whether they are due to retinal activities to be correlated with the rapid movement of the needles.

Axis of Movement

Tschermak (**6**), in an earlier investigation, noted that axis of movement was an important variable in monocular movement parallax and we, too, have examined influences due to this factor. An eyepiece, with artificial pupil of three mm. diameter and holding a Dove prism, was substituted for the eyepiece of the previous experiments; rotation of the Dove prism allowed for any desired rotation of the axis of movement. In order to determine the (zero angle) position of the Dove prism for which the stimulus needles appeared vertical, we calibrated prism rotation against a plumb-line with attached bob. The plumb-line was reflected into the observer's eye from a distance of about two feet by means of a thin glass plate, so set that the axis of rotation for reflection was parallel to the plumb-line. It was possible to look through the reflecting plate at the needles and see them and the plumb-line simultaneously. The setting of zero for the Dove prism was found for that position for which the plumb-line and needles appeared superimposed. This setting gave the prism position for a movement axis of zero degrees, i.e., horizontal movement of the needles across the field. (The needles are, of course, oriented at 90 degrees to the axis of movement.) A change in axis from 0° to 180° means that the movement remains in the horizontal plane but with the stationary needle in the lower part of the field (at 180°) rather than the upper. From 0° to 90° the stationary needle is in the upper part of the field; from 90° to 180°, it is in the lower part of the field; from 180° to 270°, it remains in the lower part of the field; and from 270° to 360°, it appears on top. Axis of movement is indicated from the zero degree position in a counterclockwise direction. A pointer soldered to the eyepiece indicated prism position on a protractor.

Three *S*s were used. Each received practice on the 90° (vertical) and three other axes of movement selected at random. Each *S* made 60 settings for each axis of movement. In each experimental session, 20 readings were made for each of 12 axes of movement spaced at intervals of 30°. Subject MS began the session with the needles moving on an axis of zero; subject SV started with the needles moving on an axis of 240°; and subject CM started with the needles moving on an axis of 120°. Rotation of the visual field was in a clockwise direction through 360°.

TABLE V

EFFECT OF AXIS OF MOVEMENT

Log ω_t for settings made with the stimulus needles moving along 12 different axes. Data are based on 20 settings at each position and for three *S*s. Brightness = 100 millilamberts. δ_t may be calculated by equation (9). Computations of δ_t as in Table III. Needle diameter = 0.025 in.

Axis of Movement in Degrees	Log ω_t			
	MS	CM	SV	Average
0	1.53	1.32	1.73	1.52
30	1.46	1.22	2.02	1.57
60	1.55	1.47	1.98	1.67
90	1.48	1.50	2.02	1.67
120	1.64	1.55	2.17	1.79
150	1.65	1.61	2.00	1.75
180	1.51	1.34	1.93	1.59
210	1.58	1.48	1.97	1.68
240	1.75	1.64	2.03	1.81
270	1.50	1.59	2.26	1.78
300	1.63	1.53	2.11	1.76
330	1.61	1.51	1.71	1.61

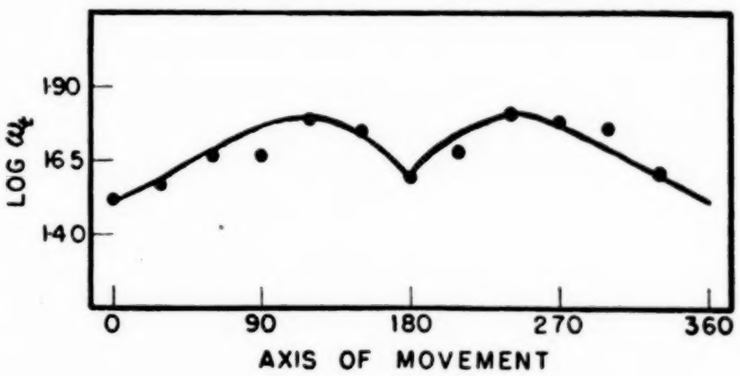

FIG. 6. Log ω_t as a function of axis of movement. Average data for three subjects are presented.

Table V presents the average experimental data for the three *S*s, two of whom (MS and CM) used the parallax cue, while the other, SV, used the coincidence cue. Fig. 6 represents average log ω_t as a function of the axis of movement. The curve shows that when the axis of movement is horizontal, log ω_t is at a minimum, while the maximum values of log ω_t are found when the axis of movement is

vertical. For axes of movement between the horizontal and vertical, the values of log ω_t become greater as the axis of movement approaches the vertical and decline as it returns to the horizontal. Day to day and *S* to *S* variability is quite large, but the log ω_t vs. *axis* plot for each subject is similar to the average curve. *S* to *S* differences appear as parameters setting the ordinate position of experimental points.

Tschermak (**6**) reports that monocular movement parallax thresholds are smaller for horizontal movement than for vertical. He found that the variation in settings, for stimuli at a distance of 21 cm., was 0.8 mm. for horizontal head movements. This value is equal to 0.032 in. and is to be compared with the values for our *S*s (0.008 to 0.031 in.) obtained with horizontal movement at a distance approximately equal (24 cm.) to that used by Tschermak. For stimuli viewed at a distance of 40 cm. and under conditions of vertical head movement, the variations of settings in Tschermak's experiment ranged from five to nine mm. (0.2 to 0.35 in.). If now, the δ_t values of the latter experiment are corrected to a distance of 20 cm., they are reduced to one-fourth their value and become 0.05 to 0.09 in. The range of Tschermak's values estimated in this way is comparable to the range of values in our experiment (0.011 to 0.065 in.) obtained at a viewing distance of 24 cm. and with vertical eye movements. Our findings thus substantiate Tschermak's conclusions that the monocular movement parallax threshold is smaller for a horizontal axis of movement than for a vertical.

It seems possible that the different threshold values for monocular movement parallax in various axes may be a function of the effectiveness of action of particular muscle pairs controlling the various axial movements. Another possible explanation may be in terms of retinal gradients whereby the number of cones per unit area varies in different manners along different foveal-peripheral axes.

Discussion

The results of our experiments indicate that space perception based on monocular movement parallax is little influenced by differences in visual angle of the objects. Monocular movement parallax thresholds are lowest for relatively high illuminations (100 millilamberts); they are influenced by the rate of movement of the objects; and they are lowest for movements along a vertical axis rather than along a horizontal axis. The preliminary nature of this research does not permit us to formulate any theoretical explanation for the results, but several comments and speculations may be made concerning them.

The cues used by the *Ss* in our experiments were of two classes: one, a coincidence 'lining up' of the objects, and the other, a discrimination based on the tridimensional appearance of the moving objects. We have shown that these judgments do not depend upon the relative sizes of the objects and we feel quite sure that no non-visual cues determined the *Ss*' responses. The use of the method of bracketing might conceivably involve kinesthetic cues, but three lines of evidence lead us to believe that this was not true. In the first place, the knob used to set the micrometer was not rigid and the amount of play involved would seem to make kinesthetic cues useless. In addition, it was found that settings made on the basis of kinesthetic cues alone, when the light in the apparatus was turned out, were very inaccurate and inconsistent. And finally, it was seen that the constant stimulus method used in two experiments yielded results similar to those obtained with the bracketing method.

The task involved in these experiments differed in its perceptual aspects among our *Ss*. Five of the *Ss* (CG, HB, JA, MS, and CM) stated that they received a true three dimensional impression when the two needles, at different distances, moved across the field. The movable needle, when not in the same plane as the stationary needle, appeared to describe a V-shaped figure, the direction of the vertex depending upon which side of the stationary needle the movable needle was placed. An impression of greater difference in distance was obtained at the two ends of the excursion, while in the center the needles appeared in the same plane. The other *Ss* saw no such phenomenon, although they reported that when the needles were not in the same plane, one appeared to approach the center of the field and then recede faster than the other. Also they noted that the needles did not appear one above the other except in the center of the field when the needles were at different distances. The latter group of *Ss* made settings in such a manner that the needles appeared to move across the field at the same rate of speed and with one always above the other, even at the extremes of the excursion where angular deviations are the greatest. Those *Ss* who saw the stimuli in three dimensional space adjusted the needles so that neither appeared to move out of a single plane throughout the excursion.

In each of the experiments both types of *Ss* were used and in all cases the results are similar in spite of perceptual differences. Since the results of all the *Ss* are comparable, it is reasonable to assume that the primary cues are the same for the two groups, perhaps coincidence acuities based on retinal diffraction patterns.

As a preliminary attempt to describe the data for log ω_t as a function of illumination, we have employed Hecht's (3) photochemical theory of vision. In our experiment, the diffraction patterns made

by the needles separated as they passed across the retina, the rate of separation depending on the difference in distance of the needles. It is assumed that a threshold rate of separation is required in order that intensity differences between the needles and the background may be perceived. This threshold rate should remain constant at any given intensity, but, as the level of illumination changes, it should vary in accordance with intensity discrimination principles.

The results of varying rates of movement are complex. Effects of varying duration of exposure and length of excursion must be examined before a basis for interpretation may be reached.

Our investigation of the effect of the axis of movement upon threshold differential angular velocity shows that the threshold for vertical movement is approximately twice that for horizontal movement, a difference compatible with that found by Tschermak (**6**) when corrections are made for his different viewing distances. We have no experimental data to explain this finding, but we suggest that it may be attributed to (a) the differences in efficiencies of various muscle pairs, or (b) the differences in sensitivity to movement of different retinal axes.

We have been unable to observe any systematic variations in the constant error of settings during the experiments. Differences between the average setting and the 'true' setting (as determined by the *E*) did occur to the extent of a few thousandths of an inch. However, the difference might on one day be positive and on the next day, negative. For example, an average of 17 determinations on five *S*s under comparable conditions gives a constant error of −0.0025 in.; of the 17 values, 7 are positive and 10 negative. In no case was the average constant error more than one-third the average δ_t for a given *S*.

Summary

1. This experiment has been concerned with certain quantitative aspects of monocular movement parallax. The effects of the following variables on monocular movement parallax measures have been determined: (a) differences in size of moving objects, (b) intensity of illumination, (c) rate of movement of objects, and (d) axis of movement of objects. Ten practiced *S*s were used.

2. A theoretical discussion has been given of the geometry of monocular movement parallax when the *S* is stationary and the viewed objects are moving. An expression has been derived for the analysis of precision data in terms of the differential angular velocity of two objects moving at equal speeds but at different distances from the observer. Threshold differential angular velocity has been designated as ω_t.

3. The apparatus used in the experiment consists of equipment whereby measurement may be made of the precision of distance settings (δ_t) of two needles, one above the other, moving at constant and equal speeds back and forth across an illuminated field. The data obtained consist of variability ($SD = \delta_t$) measures of threshold obtained from units of 20 settings; these data have been used in the calculation of ω_t [see equation (9)].

4. The results of an experiment on the effect of differences in size of the stimulus needles indicate that the settings are made on the basis of distance cues other than visual angle.

5. Log ω_t decreases with increase in the logarithm of the intensity of illumination over the cone range. The decrease is rapid at low intensities and then becomes more gradual. A final, low constant level of ω_t is reached at high intensities (about 100 millilamberts). Hecht's intensity discrimination curve is applied to the data.

6. A threefold increase in rate of movement of the needles was seen to increase ω_t by a factor of three. Control experiments indicate that the increase in ω_t at the higher rates is not due to the greater frequency of exposures at these rates, but that either or both duration of exposure and length of excursion are important variables.

7. ω_t is about twice as large for movements along the vertical axis as for movements along the horizontal axis. ω_t assumes intermediate values for axes lying between the horizontal and the vertical.

8. Discussions of many aspects of the research are presented under the appropriate treatments of experimental data.

(Manuscript received June 18, 1947)

References

1. Bourdon, B. *La perception de l'espace.* Paris: Librairie C. Weinwald, Schleicher Frères, Éditeurs, 1942, 286–288.
2. Graham, C. H. Visual perception. In: *Handbook of experimental psychology* (ed. by Stevens). (In preparation)
3. Hecht, S. A theory of visual intensity discrimination. *J. gen. Physiol.*, 1935, **18**, 767–789.
4. Helmholtz, H. L. F. von. *Treatise on physiological optics.* Trans. J. P. C. Southall. Optical Society of America, 1925. Vol. III, 295–297.
5. Shlaer, S. The relation between visual acuity and illumination. *J. gen. Physiol.*, 1937, **21**, 165–188.
6. Tschermak-Seysenegg, A. Ueber parallaktoskopie. *Pfluegers Arch. ges. Physiol.*, 1939, **241**, 454–469.

TASK–ORIENTATION AND EGO–ORIENTATION AS FACTORS IN REMINISCENCE

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Although reminiscence is now a well established phenomenon of memory,[1] the conditions giving rise to reminiscence have not been clearly established. Some investigators find a memory increment (reminiscence) when the recall of incompletely learned material is measured some time after the original learning; others, using seemingly not too different techniques, do not. Current theories of reminiscence (**4**, **13**, **15**, **17**), moreover, cannot explain this 'now-you-see-it-now-you-don't character of reminiscence research' (**4**, p. 337).

A learning and retention study reported by Alper (**2**) in 1946, although not designed to investigate reminiscence as such, introduced parameters which seem to be important for reminiscence, as well as for other aspects of learning and retention. These parameters were termed *task-orientation* and *ego-orientation*, respectively. An *S* is said to be task-oriented if the experimental instructions stress the task, or work to be done, rather than *S*'s performance on that task. An *S* is said to be ego-oriented if the experimental instructions stress *S*'s ability to perform on that task.[2] Task-oriented learning was found to be superior to task-oriented retention. Ego-oriented learning, however, was not superior to ego-oriented retention. Further statistical analyses of these findings bearing on the problem of reminiscence are presented in the present paper.

These analyses indicate that ego-oriented retention differs from task-oriented retention 24 hours after learning in two important ways:

[1] See Buxton (**4**) and McGeoch (**15**) for extensive reviews of the earlier literature in this field.

[2] Note that the term 'task-orientation' does not necessarily imply 'task-involvement.' Nor does the term 'ego-orientation' necessarily imply 'ego-involvement.' In a friendly, casual, laboratory setting, *E intends* to task-orient the *S* by an instruction such as, "I want to find out something about these materials; so try to learn the series." *E* does not thereby assure that ego-needs are not aroused, that the *S* is merely task-involved. Similarly, when *E* instructs the *S*, "This is an intelligence test," *E intends* that ego-needs be aroused, that *S* feel that his self-esteem is being threatened and that he may be 'shown up.' But again, *E*'s intention does not assure that *S* will accept the instructions in this way, that ego-needs actually will be threatened, and hence that *S* will be ego-involved. The *Aufgabe* does not automatically establish the mental set intended by the *E* (cf. Alper, **2**). Some *S*s are ego-involved, regardless of *E*'s instructions, by virtue of the fact that the laboratory situation is itself an ego-threat. Other *S*s can remain merely task-involved under these same circumstances. The orientation, not the involvement, therefore, is operationally determined by the nature of *E*'s instructions. The nature of the involvement, on the other hand, can be shown to be a function of the personality structure of the individual rather than of the orientation alone (**1**).

(1) the ego-oriented *S* recalls *new* items not previously reproduced in the original learning situation, while the task-oriented *S* typically recalls no new items; and (2) the ego-oriented *S* shows only a negligible loss of previously reproduced items, while the task-oriented *S* shows a significant memory decrement. In other words, reminiscence, or the recall of new items, would seem to be a phenomenon of ego-oriented but not of task-oriented learning. A survey of earlier reminiscence studies in the light of these parameters helps to establish order in this otherwise unordered field.

Procedure

The procedure for this experiment has been reported in detail elsewhere (2). Briefly, Siegel's (19) 20-item series of nonsense syllables and three place digits was shown through twice to 40 Radcliffe undergraduates. Half of the *S*s were told that the ability to learn the series would be used as a measure of their intelligence, and half were not. In addition, half of the first (ego-oriented) and half of the second (task-oriented) group were required to write each item on a separate piece of paper while the item was being presented. The others were not given this instruction. Thus, 10 ego-oriented *S*s were 'active' during the two learning trials and 10 were 'inactive.' Similarly, 10 task-oriented *S*s were 'active' and 10 were 'inactive.' Following Jenkins' (7) technique, half of the *S*s in each subgroup served as *E*s (SE), and half as *S*s (SS). The SS's were explicitly told to learn the series. The SE's were not told to do so. This subdivision had been introduced in the original experiment in order to test differences between incidental and intentional learning and memory under conditions of task- vs. ego-orientation. But since these parameters yielded no significant differences pertinent to the reminiscence data, the SE–SS subgroups have been retained in Tables I–V which follow, but are not separately discussed.[3]

After the series had been presented through twice, all *S*s were required to write down as many items of the series as they could remember. The number of items correctly reproduced at this time, Day I, was used as a measure of learning. An item was scored as correct if it was reproduced exactly, regardless of the serial order of recall.

None of the *S*s was told on Day I that there would be a recall test 24 hours later on Day II, and there was no formal practice of the series between Day I and Day II. The number of items correctly recalled on Day II was used as a measure of retention. An item was scored as correctly recalled if it was recalled exactly, regardless of the serial order of recall.

The standard conditions for testing for reminiscence by Ballard's (3) test-retest technique obtained, therefore, in this experiment: the material was incompletely learned by all *S*s; learning was tested in the learning

[3] Differences between the SE–SS subgroups may have been eliminated in this experiment by the tendency of SE's to give themselves self-instructions to learn the series (2). Under such conditions, the classical conditions for incidental learning would not have pertained.

situation on Day I; retention was measured by a recall test after a 'rest' interval; and no formal practice intervened between the original learning trials and the recall test.

All *Ss* were asked at the end of the experiment on Day II whether they had tended to rehearse the series during the 24 hour 'rest' interval.

Results

Part I: The Role of Orientation in Reminiscence

Traditionally, reminiscence has been measured by testing either the absolute differences or the percentage differences between the retention of incompletely learned material and the original reproduction of this material. If the recall score of a given *S* is higher than his learning score, a positive retention difference score results. Such positive retention difference scores have been taken as evidence for reminiscence.

The traditional type of analyses of the differences obtaining between retention and learning scores in the present data is shown in Tables I–III, below. Separate analyses of memory loss, or the number of items originally reproduced on Day I but not later recalled on Day II, and of memory gain, or the number of *new* items recalled on Day II which had not been reproduced on Day I, appear in Tables IV and V.

The mean differences between total recall scores on Day II and

TABLE I

Mean Retention Difference Scores of Each of the Eight Groups of *Ss*

	Task-Orientation		Ego-Orientation	
	Active	Inactive	Active	Inactive
SE	−2.1	−1.8	+0.8	−0.6
SS	−1.4	−2.6	+0.2	−1.6
Mean	−1.8	−2.2	+0.5	−1.1

TABLE II

Retention Difference Scores of Ego-oriented *Ss* Analyzed by Means of the Analysis of Variance Technique

Source of Variation	d.f.	Sum of Squares	Mean Square	*F*	*P*
Total	19	58.2			
1. Activity-inactivity	1	12.8	12.8	4.87	.05
2. SE-SS	1	3.2	3.2	1.22	
Interaction	1	.2	.2		
Error	16	42.0	2.63		

TABLE III

RETENTION DIFFERENCE SCORES OF TASK-ORIENTED *Ss* ANALYZED BY MEANS OF THE ANALYSIS OF VARIANCE TECHNIQUE

Source of Variation	d.f.	Sum of Squares	Mean Square	*F*	*P*
Total	19	30.0			
1. Activity-inactivity	1	.8	.8		
2. SE-SS	1	0.0	0.0		
Interaction	1	3.2	3.2	1.96	
Error	16	26.0	1.63		

TABLE IV

MEMORY LOSS: MEAN NUMBER OF ITEMS REPRODUCED ON DAY I BUT NOT RECALLED ON DAY II BY EACH OF THE EIGHT GROUPS OF *Ss*

	Task-Orientation		Ego-Orientation	
	Active	Inactive	Active	Inactive
SE	2.2	1.8	0.6	1.4
SS	1.8	2.6	1.2	2.0
Mean	2.0	2.2	0.9	1.7

TABLE V

MEMORY GAIN: MEAN NUMBER OF NEW ITEMS RECALLED ON DAY II BY EACH OF THE EIGHT GROUPS OF *Ss*

	Task-Orientation		Ego-Orientation	
	Active	Inactive	Active	Inactive
SE	0.0	0.0	1.4	0.8
SS	0.4	0.0	1.0	0.4
Mean	0.2	0.0	1.2	0.6

total immediate reproduction scores on Day I are given for each group of *Ss* in Table I. These difference scores will be referred to as the retention difference scores. A negative retention difference score would indicate that retention on Day II was poorer than learning on Day I. A positive score would indicate a memory gain on Day II. A score of zero would indicate that *S* recalled the same number of items on Day I and on Day II.

The analysis of these retention difference scores, by means of the analysis of variance,[4] discloses only two statistically significant reten-

[4] Clearly with material of this sort there is the possibility that the correlation between initial learning scores and later recall scores could be important. An analysis of covariance, however, showed no such relationship. The regression coefficient was found to be .13. It was decided, therefore, to present the data in the simpler form of the analysis of the difference variances rather than in the form of covariance.

tion difference score relationships. (1) Ego-orientation yields significantly higher retention difference scores than task-orientation. The mean score for all ego-oriented *Ss* is −0.3 items; for all task-oriented *Ss*, −2.0. In other words, ego-oriented *Ss* tend to recall about as many items as they originally reproduced in the learning situation, while task-oriented *Ss* recall fewer items than they originally reproduced. The difference between ego-oriented and task-oriented retention difference scores is significant well beyond the .001 level of confidence ($F = 13.57$, one degree of freedom). (2) Activity yields significantly higher retention difference scores than inactivity. The mean score for all active *Ss* is −0.65 items; for all inactive *Ss*, −1.65. This difference is significant at the .05 level of confidence ($F = 4.70$, one degree of freedom). Ego-orientation aids retention, then, and so does activity.

Within the limits of this experiment, however, activity aids retention only under conditions of ego-orientation. In Tables II and III, the data for ego-orientation and task-orientation are analyzed separately to show this fact. Retention difference scores of active ego-oriented *Ss* are significantly higher than those of inactive ego-oriented *Ss*. The mean score for the active *Ss* is +0.5 items; for inactive *Ss*, −1.1. Active ego-oriented *Ss*, in other words, recall on the average *more* items than they originally reproduced, while inactive ego-oriented *Ss* recall on the average *fewer* items than they originally reproduced. This difference between active ego-oriented and inactive ego-oriented *Ss* is significant at the .05 level of confidence ($F = 4.87$, Table II). Both active and inactive task-oriented *Ss* retain *fewer* items than they originally reproduced. The mean score for the former is −1.8 items; for the latter, −2.2. This difference is not statistically significant (cf. Table III).

Although the analyses in Tables I–III leave no doubt concerning the advantages for retention of ego-orientation in general, and of active ego-orientation in particular, reminiscence data as such are not clearly partialed out. In fact, the traditional method of analyzing retention data, as followed in Tables I–III, indicates the presence of reminiscence only for active ego-oriented *Ss*, since this group alone obtained a mean positive retention difference score. This method of analyzing retention difference scores, however, confounds memory loss over a given period of time with memory gain over this same period of time. Thus, while a positive difference score in Table I of necessity indicates the recall of new items not previously reproduced in the learning situation, a negative score indicates only that the total number of items recalled was less than the total number originally reproduced. A score of zero, moreover, indicates merely that the same total number of items was recalled as was reproduced.

No differentiation is made between the recall of new and old items in this type of analysis. In order to determine, therefore, whether individual memory gains under any conditions of the experimental design have been counterbalanced by individual memory losses in such manner that an *S*'s total retention difference score would be zero, or even negative, retention difference scores must be broken down into memory loss of previously reproduced items and memory gain of new items. The term 'reminiscence' could then be limited to this latter more sensitive measure of memory gain, namely, the recall of new items not previously reproduced. The term 'forgetting' has already been generally applied to the memory loss, or failure to recall previously reproduced items.

To separate forgetting and reminiscence, the retention data of Table I were broken down as shown in Tables IV and V. Memory loss differences are analyzed in Table IV; memory gain, or reminiscence, in Table V.

Memory loss

The memory loss data analyzed in Table IV involve only the absolute difference for each *S* between the number of items reproduced on Day I and the recall of these *same* items on Day II. This analysis shows that ego-oriented *S*s have a significantly smaller memory loss than task-oriented *S*s. The mean loss of ego-oriented *S*s was 1.3 items; for task-oriented *S*s, 2.1 items. This difference, when analyzed by means of the analysis of variance technique, is found to be significant at the .05 level of confidence ($F = 4.18$, one degree of freedom).

Moreover, whereas all task-oriented *S*s show some memory loss on Day II, 35 percent of the ego-oriented *S*s recall all of the items they originally reproduced on Day I and thus show no memory loss at all on Day II. This percentage difference between ego-oriented and task-oriented *S*s is significant beyond the .01 level of confidence.[5] It is clear, therefore, that ego-oriented *S*s are less likely than task-oriented *S*s to show a memory loss after a 24 hour 'rest' interval. The relationship of this finding to the classical task-oriented Ebbinghaus (**5**) retention curve has already been discussed by Alper (**2**) elsewhere.

Memory gain

The number of *new* items recalled on Day II which were not reproduced on Day I represents the memory gain to which, it is

[5] Zubin's (**23**) nomographs have been used for testing the significance of the difference between percentages.

suggested here, the term reminiscence be restricted. These data are shown in Table V. The mean gain for all ego-oriented *Ss* is 0.9 items; for task-oriented, 0.1. The difference between ego-oriented and task-oriented memory gains, when analyzed by means of the analysis of variance technique, is found to be significant beyond the .001 level of confidence ($F = 16.4$, one degree of freedom). Moreover, whereas 60 percent of the ego-oriented *Ss* show some memory gain, only 10 percent of the task-oriented *Ss* show a gain. The significance level of this percentage difference is beyond the .01 level of confidence. It is clear, therefore, that ego-orientation is more likely than task-orientation to yield reminiscence data. This fact was embedded in the retention difference scores of Table I but could be demonstrated more clearly by a separate analysis of memory loss and memory gain scores.

Activity also makes a difference in reminiscence. Active *Ss*, regardless of orientation, show a greater absolute memory gain than do inactive *Ss*. The difference between activity and inactivity, when analyzed by means of the analysis of variance technique, is found to be significant at the .05 level of confidence ($F = 4.10$, one degree of freedom).

Activity alone, however, is not a sufficient condition to assure reminiscence. Within a given orientation, activity tends to be the superior condition for reminiscence. But the differences between the absolute number of new items recalled by active ego-oriented *Ss* as compared with inactive ego-oriented *Ss*, and of active task-oriented as compared with inactive task-oriented *Ss*, are not statistically significant. Thus, although activity is a superior condition for ego-oriented retention (Table II), activity *qua* activity is not necessarily a superior condition for reminiscence (Table V).

Within the limits of this experiment, therefore, when memory gain is analyzed separately from memory loss, ego-orientation is the basic parameter favoring the recall of new items. Activity tends to be superior to inactivity both within ego-orientation and task-orientation, but activity alone does not assure reminiscence.

Part II: The Role of Rehearsal in Reminiscence

One of the factors which investigators of reminiscence have considered is the role of rehearsal in reminiscence. The experimental evidence from previous studies is decidedly equivocal. Some investigators consider rehearsal important, others do not. With few exceptions, therefore, rehearsal has been negated.[6] Yet in the present

[6] See Buxton (4) and McGeoch (15) for summaries of the rehearsal literature as related to reminiscence.

experiment, under certain experimental conditions, rehearsal does seem to have been an important factor.

When asked at the end of the experiment on Day II whether they had tended to rehearse the series during the 24 hour interval between reproduction and recall, 15 of the 20 ego-oriented *Ss* answered 'Yes'; five answered 'No.' Task-oriented *Ss*, on the other hand, were evenly divided in their tendency to rehearse: 10 said 'Yes' and 10 said 'No.'

Within the ego-oriented groups all 10 of the active ego-oriented *Ss* reported rehearsal. Of the inactive ego-oriented *Ss*, five reported rehearsal and five no rehearsal. Within the task-oriented groups activity seems to have been less important: six of the active task-oriented *Ss* reported rehearsal, four no rehearsal; four of the inactive task-oriented *Ss* reported rehearsal and six no rehearsal. Thus, 16 active *Ss* and nine inactive *Ss*, disregarding differences in orientation, report rehearsal and four active and 11 inactive *Ss* report no rehearsal. The analysis of these differences by the chi-square test, corrected for continuity by Yates' correction, is shown in Table VI.

TABLE VI

ANALYSIS OF THE NUMBER OF *Ss* REPORTING REHEARSAL OR NO REHEARSAL DURING THE TWENTY-FOUR HOUR 'REST' INTERVAL
Chi-square values corrected for continuity

Condition	Rehearsal	No Rehearsal	x^2	P (1 d.f.)
Ego-orientation	15	5	1.71	.20–.10
Task-orientation	10	10		
Activity	16	4	3.84	.05
Inactivity	9	11		
Active ego-orientation	10	0	4.27	.05–.02
Inactive ego-orientation	5	5		
Active task-orientation	6	4	.20	.70–.50
Inactive task-orientation	4	6		

It is clear from Table VI that, although more ego-oriented *Ss* *tend* to rehearse, the difference between ego-oriented and task-oriented *Ss* is not large enough to be statistically significant. Yet, in view of the later breakdowns, the direction of the tendency in favor of ego-orientation should not be disregarded. Active ego-oriented *Ss* do significantly report rehearsal more often than inactive ego-oriented *Ss*. The difference here is significant beyond the .05 level of confidence. No such difference holds for task-oriented *Ss*. The condition most favorable for rehearsal during the 24 hour 'rest' interval, then, was active ego-orientation. It has already been shown earlier

in this report that this was also the most favorable condition for reminiscence.

Activity *qua* activity, also, seems to have been a factor favoring rehearsal: the difference between active and inactive *Ss* is significant at the .05 level of confidence. A similar difference in favor of active *Ss* was found for reminiscence.

The mere tendency to rehearse, however, is not a sufficient condition to assure reminiscence. As shown in Table VII, 10 task-

TABLE VII

ANALYSIS OF THE RELATION BETWEEN REPORTED REHEARSAL AND REMINISCENCE
Chi-square values corrected for continuity

Condition	No. of *Ss* who Report Rehearsal and Show Reminiscence	No. of *Ss* who Report Rehearsal and Show No Reminiscence	χ^2	*P* (1 d.f.)
Task-orientation	2	8	6.50	.02–.01
Ego-orientation	12	3		

oriented *Ss* acknowledge rehearsal but only two of the 10 show reminiscence. Fifteen ego-oriented *Ss* acknowledge rehearsal and 12 show reminiscence. The difference between these two groups is well beyond a chance difference. The χ^2 value, corrected for continuity, is 6.50. This is significant between the .02 and the .01 level of confidence. The ego-oriented *S* who rehearses during the 'rest' interval, therefore, is more likely to reminiscence than the task-oriented *S* who rehearses during the 'rest' interval.

Taking the rehearsal data at face value, then, it would seem that rehearsal may play an important but not all-explanatory role in reminiscence. Rehearsal aids, but does not assure, reminiscence. The more basic factor seems to be the orientation of the *S* at the time of original learning.[7]

DISCUSSION

Previous studies in the field of learning and memory had established the fact that reminiscence occurs under a variety of experimental conditions. The specific conditions which must pertain in order for reminiscence to appear, however, had not been unequivocally

[7] The fact that 50 percent of the task-oriented *Ss* report rehearsal is in itself an important finding. It may be that, although experimentally task-oriented, task-oriented *Ss* who answered 'Yes' to the rehearsal question actually were to some extent ego-involved by virtue of the fact that they were being tested in a psychological laboratory. The presumption here is that the behavior of the task-oriented, ego-involved *S* would resemble that of the ego-oriented *S*. This presumption is in accord with the findings of Alper (1), Lewis and Franklin (12), Zeigarnik (22), and many others, that some task-oriented *Ss* react as if the test situation were a personal threat. Personality factors would play an important and deciding role here, as has been suggested elsewhere by Alper (1).

established. The results of the present experiment indicate that an important, and seemingly basic, condition for the correct recall of items not previously reproduced in the original learning situation is the mental set of the *S* at the time of the original learning. If the learning takes place under conditions of ego-orientation, after a 24 hour 'rest' interval new items are correctly recalled. If the learning takes place under conditions of task-orientation, a memory loss, not a memory gain, is found. In other words, regardless of the methodology of the particular experiment, it may be that where reminiscence has been found in the past more *S*s were ego-involved than were task-involved, even though the *E* had not intended by his instructions to ego-orient the *S*s.

The importance of mental set in certain higher mental processes has been recognized ever since the early work of Külpe (**10**) and his followers in the Würzburg school. It is not surprising, therefore, to find that mental set plays an important role in reminiscence. Why it functions as it does in reminiscence still needs to be explained, however.

The data of the present experiment can be conceptualized within the framework of studies in the recall of completed and incompleted tasks. Such studies have shown that the tension-systems established when *S* first has contact with the test material determine in large measure the nature of his subsequent recall behavior (cf., for example, **1**, **8**, **13**, **18**, **22**). Thus, Kendig (**8**) has shown that perseveration is more likely to occur if *S* experiences the initial task as a 'failed' intelligence test rather than as a casual laboratory task. In the terminology used in the present paper, this would mean that ego-oriented *S*s perseverated, task-oriented *S*s did not.

In the field of reminiscence proper, Martin (**13**) found that incompleted tasks yield a greater degree of reminiscence than completed tasks if recall is tested within two minutes after the original learning. With longer time intervals, completed tasks are more likely to be reminisced than incompleted tasks. Such findings are completely in line with Zeigarnik's (**22**) pioneer studies in the field of memory for completed and incompleted tasks: the incompleted task leaves behind it an unresolved tension-system, or need for completion. Other things being equal, this tension-system endures for a limited period of time and assures the recall of incompleted tasks.

The present data go beyond such studies by contributing further to our understanding of the nature and course of different types of tension-systems and of the *particular* conditions under which incompleted tasks are likely to yield reminiscence data. The fact of incompletion *per se* is not sufficient to assure reminiscence.

In the present experiment, the instructions were designed to arouse task-tensions in half of the *S*s, and ego-tensions in the other half. The series was incompletely learned by all *S*s. It might be expected, therefore, that incompleted task-tensions would be aroused in all *S*s and that the need to complete the task would be equally strong in all *S*s. The obtained facts were, however, that ego-oriented *S*s showed a significantly lower memory loss than did task-oriented *S*s, and that only ego-oriented *S*s gave evidence of reminiscence. To these facts can be added the data on rehearsal: ego-oriented *S*s, especially if active during the original learning, were more likely than not to rehearse the test series during the 'rest' interval; task-oriented *S*s were equally likely to rehearse or not. Since rehearsal may be regarded as a means of completing an incompleted task, this difference in the tendency or *need to rehearse* under the different experimentally induced orientations may be of basic importance.

Task-tensions are aroused when task-centered needs alone are involved. Ego-tensions are aroused when status or self-esteem is threatened. Reproduction, recall after a 'rest' interval, or rehearsal during the 'rest' interval can effectively resolve task-tensions. All of these are less effective in resolving ego-tensions than task-tensions, however. So long as all of the items in the test series are not recalled, the ego-threat remains. Thus, since the tensions persist, the *S*'s need to rehearse during the 'rest' interval persists. With the additional practice which the rehearsal affords, come both the smaller memory loss and the superior memory gain of these *S*s. This mechanism shows itself most clearly in the case of active ego-oriented *S*s where the tension or vigilance level is raised on two counts: (1) the ego-threat derived from the orientation and (2) the additional practice afforded by the activity itself.

If, as has been suggested above, task-tensions are more readily resolved than ego-tensions, this fact will explain certain discrepancies in the earlier reminiscence literature. In the absence of an ego-threat, even a single reproduction of the test series should be capable of resolving task-tensions. Thus, in the Ballard (3) and Williams (21) test-retest technique, where the *S* is required to reproduce the series in the learning situation, the task-oriented or task-involved *S* *can* resolve residual task-tensions by this single reproduction. This reproduction would not necessarily resolve residual ego-tensions, however, if ego-needs had been aroused. Reminiscence would occur, therefore, when the test-retest technique was used only if ego-tensions had been experimentally aroused in the original learning situation. This was the finding in the present experiment.

If the *S* is not allowed to reproduce the series in the learning situation, as in the Ward (20) and Hovland (6) technique, it is conceivable that reminiscence could occur if either task- or ego-tensions have been experimentally aroused, *and if the time interval between presentation and recall is short enough*,

say a matter of a few minutes. Since the Ward-Hovland methodology provides no opportunity for the resolution of tensions in the learning situation, even task-tensions would persist for a short period of time and reminiscence could occur. With a longer 'rest' interval, say a day, a week, or two weeks, however, task-oriented reminiscence would not occur. Unlike ego-tensions, task-tensions do not persist over a long period of time essentially because they serve no ego-need (cf. Koffka, **9**, pp. 333–342). The presence or absence of reminiscence, therefore, is not dependent so much on the particular methodology of the experiment as on the experimentally induced orientation of the *S*s, and on the time interval between learning and recall.[8]

Another rather puzzling discrepancy in the reminiscence literature, namely, the fact that children show more reminiscence than adults, can also be resolved by the present findings. As Martin (**13**, p. 33) has already pointed out in connection with Zeigarnik's (**22**) results, children accept "the necessity for completing each (incompleted) task as more nearly a 'real need' while for the adults completion merely represented a 'quasi-need.' . . . Real needs are more fundamental and vital to the individual . . . while quasi-needs are those involving volitional consent and result from purpose or intention." What Martin seems to be saying here is that children show more reminiscence than adults because children are more likely to be ego-involved even though merely task-oriented. "The conditioning factor," he says, "is not so much age as such, but rather the nature and structure of the trace and tension systems characteristic of different age levels but not necessarily peculiar to those age levels." The young child and the adult may both be ego-involved. And, if ego-involved, both should show reminiscence.[9]

The fact that active *S*s in the present experiment showed significantly more reminiscence than inactive *S*s is not independent of the theory of reminiscence outlined above. Activity in this experiment consisted in writing each item on a separate slip of paper during the learning trials. Activity, therefore, provided these *S*s with additional practice of the series in the learning situation (**2**), and as such should aid reminiscence (cf. Raffel, **16**). Such activity, moreover, would not be likely to resolve either task- or ego-tensions, since under the given experimental conditions this activity would neither objectively nor subjectively complete the experimentally imposed task.

[8] The fact that Rosenthal (**17**) did not find reminiscence among ego-oriented *S*s in the waking state after a 15 min. interval between learning and recall, though he did find it in the hypnotic state, suggests that under ordinary waking conditions ego-orientation may set up an emotional block which prevents the *immediate* availability of these traces. It may be that it takes time for such emotional blocking to wear off. Experiments are now in progress to test this hypothesis.

[9] It is interesting to note that Leavitt (**11**) reports reminiscence with pursuit-meter material, not with nonsense syllable material. His instructions with both types of material were such as to induce a task-oriented mental set. His failure to find reminiscence with nonsense syllables, therefore, is not surprising. With the pursuitmeter, however, it is quite likely that ego- rather than task-tensions actually were aroused since this task is quite typically a frustrating, ego-involving task, irrespective of the particular experimental instructions.

In fact, the results of the present experiment indicate that activity may increase rather than decrease both task- and ego-tensions: active *Ss*, regardless of orientation, showed a significantly greater than chance tendency to rehearse during the 'rest' interval as compared with inactive *Ss*. Activity may tend to raise the tension level of the *S* during the original learning in much the same way that ego-orientation raises tension-level. To be required to write down the items in a series during the learning trials may be interpreted by the *S* as a much less casual situation even under task-orientation than merely to have to listen to the series. Activity, then, may unwittingly ego-involve the *S*. If this theory be valid, one would expect that active ego-oriented *Ss* would show more reminiscence than any other group. This was found to be the case in the present experiment.

The theory of reminiscence outlined above does not preclude a differential forgetting theory as championed by Buxton (**4**), McGeoch (**15**), and others. On the contrary, it supplements a theory of differential forgetting in that it calls attention to the role of intrapersonal inhibitions in addition to intraserial inhibitions. According to the differential forgetting theory, intraserial inhibitions are built up during the learning period. Such interferences are postulated to be 'less well fixated' (**4**, p. 350) than the correct responses and are, therefore, more rapidly forgotten during the 'rest' interval. Freed of these interferences after the 'rest' interval, the correct responses appear more readily than during the learning period, and new items, not previously reproduced, may be recalled. It is entirely consistent with this theory to postulate that the arousal of ego-needs under conditions of ego-orientation introduces additional intrapersonal interferences, or emotional blocks, which inhibit reproduction. If, during the 'rest' interval, ego-tensions are diminished, intrapersonal as well as intraserial inhibitions would drop out and correct items would be freer to appear in the recall test than in the reproduction test. Since ego-oriented reproduction is subject both to intrapersonal and to intraserial inhibitions, while task-oriented reproduction is subject only to the latter, it follows that ego-oriented learning would not necessarily be superior to task-oriented learning (**2**). Granted the present time-intervals between learning and recall, ego-oriented retention and ego-oriented reminiscence, however, should be superior to task-oriented retention and to task-oriented reminiscence, respectively, as was found in the present experiment.[10]

[10] McClelland and Apicella (**14**) have recently formulated a 'removal of inhibition' theory of reminiscence. The theory outlined above is quite consistent with that of McClelland and Apicella. The present writer, however, is not of the opinion that such a theory either replaces entirely or is inconsistent with a differential forgetting theory.

Summary

The data of a previously reported study in learning and retention are reanalyzed here to show the importance for reminiscence of parameters which had not been treated by earlier investigators in this field. These parameters were termed task-orientation and ego-orientation, respectively.

The major findings pertinent to reminiscence are:

1. Reminiscence after a 'rest' interval as long as 24 hours occurs under conditions of ego-orientation, not task-orientation.

2. Activity is a less important parameter for reminiscence than ego-orientation. Activity aids reminiscence only if the *S* is ego-oriented.

3. Differences in mental set may be experimentally induced or self-induced. The failure to control such differences in previous studies in this field could account for what Buxton (4) has termed 'the-now-you-see-it-now-you-don't character of reminiscence research.'

4. The conditions associated with rehearsal are also associated with reminiscence. Active *S*s, and especially active ego-oriented *S*s, report rehearsal during the 'rest' interval. The mere tendency to rehearse, however, is not a sufficient condition to assure reminiscence.

5. Reminiscence data can be conceptualized within the framework of studies in the field of completed and incompleted tasks. The ego-oriented *S* experiences the learning situation as a threat to his self-esteem. Ego-tensions thus aroused persist in time and are available for rehearsal during the 'rest' interval, and for recall in the recall test. Ego-oriented rehearsal persists because it serves an ego-need. The task-oriented *S* experiences the incompletion of the learning situation merely as an incompleted task. Task-tensions alone are aroused. Since task-tensions serve no ego-need, they do not persist in time. Task-oriented rehearsal resulting in task-oriented reminiscence, therefore, is rare. In other words, incompletion *qua* incompletion does not assure reminiscence.

6. The theory of reminiscence suggested above is consistent with, and supplemental to, the widely accepted theory of differential forgetting.

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References

1. Alper, T. G. Memory for completed and incompleted tasks as a function of personality. *J. abnorm. soc. Psychol.*, 1946, **41**, 403–420.
2. Alper, T. G. Task-orientation vs. ego-orientation in learning and retention. *Amer. J. Psychol.*, 1946, **59**, 236–248.

3. Ballard, P. B. Obliviscence and reminiscence. *Brit. J. Psychol., Monogr. Suppl.*, 1913, 1, No. 2.
4. Buxton, C. E. The status of research in reminiscence. *Psychol. Bull.*, 1943, **40**, 313–340.
5. Ebbinghaus, H. *Memory: a contribution to experimental psychology.* (Trans.) New York: Teachers College, Columbia Univ., 1913.
6. Hovland, C. I. Experimental studies in rote-learning theory: I. Reminiscence following learning by massed and by distributed practice. *J. exp. Psychol.*, 1938, **22**, 201–224.
7. Jenkins, J. G. Instruction as a factor in 'incidental' learning. *Amer. J. Psychol.*, 1933, **45**, 471–477.
8. Kendig, I. Studies in perseveration: II. Determining factors in the development of compulsive activity. *J. Psychol.*, 1936, **3**, 231–246.
9. Koffka, K. *Principles of gestalt psychology.* New York: Harcourt, Brace, 1935.
10. Külpe, O. Versuche über Abstraktion. Ber. I. *Kongr. exp. Psychol.*, 1904, **I**, 58–68.
11. Leavitt, H. J. The relation of speed of learning to amount retained and to reminiscence. *J. exp. Psychol.*, 1945, **35**, 134–140.
12. Lewis, H. B., & Franklin, M. An experimental study of the role of the ego in work. II. The significance of task-orientation in work. *J. exp. Psychol.*, 1944, **34**, 195–215.
13. Martin, J. R. *Reminiscence and gestalt theory. Psychol. Monogr.*, 1940, **52**, No. 235.
14. McClelland, D. C., & Apicella, F. S. Reminiscence following experimentally induced failure. *J. exp. Psychol.*, 1947, **37**, 159–169.
15. McGeoch, J. A. *The psychology of human learning.* New York: Longmans, Green, 1942.
16. Raffel, G. The effect of recall on forgetting. *J. exp. Psychol.*, 1934, **17**, 828–838.
17. Rosenthal, B. G. Hypnotic recall of material learned under anxiety and non-anxiety producing conditions. *J. exp. Psychol.*, 1944, **34**, 369–389.
18. Rosenzweig, S. Experimental study of repression with specific reference to need-persistive and ego-defensive reactions to frustration. *J. exp. Psychol.*, 1943, **32**, 64–74.
19. Siegal, P. Structure effects within a memory series. *J. exp. Psychol.*, 1943, **38**, 507–517.
20. Ward, L. B. Reminiscence and rote learning. *Psychol. Monogr.*, 1937, **49**, No. 220.
21. Williams, O. A study of the phenomenon of reminiscence. *J. exp. Psychol.*, 1926, **9**, 368–387.
22. Zeigarnik, B. Das Behalten erledigter und unerledigter Handlungen. *Psychol. Forsch.*, 1927, **9**, 1–85.
23. Zubin, J. Nomographs for determining the significance of the differences between the frequencies of events in two contrasted series or groups. *J. Amer. statis. Ass.*, 1939, **34**, 539–544.

REMINISCENCE IN MOTOR LEARNING AS A FUNCTION OF LENGTH OF INTERPOLATED REST

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Introduction

In Hull's statement of the Mowrer-Miller hypothesis (**2**), it is postulated that all effortful responses, whether reinforced or not, produce in the organism a tendency to avoid the repetition of the response. This hypothetical inhibitory effect has been termed reactive inhibition (I_R). Reactive inhibition is regarded as a negative drive state which is essentially a need to cease action. In this sense at least, I_R is closely related to what is popularly called fatigue. The effect of I_R upon the learning process is to reduce the work-output level of the organism and to obscure the actual strength of the habit. Thus, an individual developing a habit of a given strength under conditions which tend to produce a large amount of reactive inhibition will perform less efficiently than he would with the same habit strength if the amount of I_R accumulated were not so great.

There are two experimental conditions which favor the accumulation of large amounts of reactive inhibition. The first of these involves the amount of physical work required of the subject: The more effortful the responses involved, the greater the amount of I_R. The second condition involves the rate of reaction evocation: If the organism is forced to respond rapidly, reactive inhibition will develop more rapidly than if he is allowed to rest between reactions. The second of these conditions is effective in the production of I_R because reactive inhibition is a drive state. Drives tend to diminish under the influence of the appropriate goal situation; and, for I_R, the appropriate goal is resting. Any learning situation which gives the individual a chance to rest will, therefore, provide for the reduction of reactive inhibition. Hull has made the specific statement that I_R dissipates as a simple decay function of the amount of time allowed for rest.

The tendency for reactive inhibition to accumulate with rapid elicitation of the response and to decay with time explains two important classes of results in learning experiments. The first of these is the well-known superiority of spaced over massed practice. During the rest-pauses in distributed learning, the reactive inhibition developed in the previous learning trial will disappear. As a result, the

habit will express itself to a greater extent in spaced learning than under conditions of massed practice when I_R is given little opportunity to dissipate. Secondly, if practice is given with massed reinforcements and then a pause occurs, by the same principle, the phenomenon known as reminiscence will appear. As the reactive inhibition which has accumulated during massed practice decays with rest, the response level will increase. Since I_R theoretically dissipates as a simple decay function of time, the amount of reminiscence will be greater with greater periods of rest. There will be a point, however, beyond which rest periods will be ineffective in raising the level of performance because the decay function of I_R is an asymptotic one.

Purpose of Experiment

The present experiment was designed to investigate reminiscence in motor learning as a function of length of interpolated rest, with special attention to the temporal interval at which the maximal effect takes place. To this end, six groups of *S*s received 10 practice trials on the pursuit rotor after which they were given two reminiscence trials at intervals of 10, 30, 150, 300, 600, and 1200 sec. Results obtained in this fashion should provide a relatively direct measure of the function according to which I_R dissipates with periods of inactivity. Following Hull's theoretical formulation, one would predict that, in such an experiment, performance on the reminiscence trials would be better than just prior to rest; that the amount of gain would be greater with greater periods of rest up to a point; and that, beyond this point, further rests would produce no further increase in reminiscence.

Experimental Technique

Apparatus

The apparatus used was a modified Koerth pursuit rotor, constructed from an adjustable phonograph motor, set to run at a speed of one r.p.s. The turntable was a disc of Prestwood, 15 in. in diameter. It carried a silver target the size of a dime set flush with its surface. The contact stylus was made from a 6¼ in. length of 16-gauge copper rod. A 90-degree bend was made ¾ in. from the contact end which was tipped with silver. The other end of the rod was attached, through a hinged joint, to a wooden handle in such a fashion that the contact could be guided laterally, but could not be forced down against the target. Contact between the silver tip of the stylus and the target closed the circuit through a transformer and a Stoelting electric impulse counter. This permitted a cumulative reading (in .01 sec.) of the duration of all contacts during the 50 sec. trial. The buzz of the counter acted as a signal to the *S* that he was on the target; it probably had some 'reward' value.

Subjects

A total of 93 *S*s was used in the experiment. They were all male college students ranging in age from 17–30. Most of the *S*s were recruited from the elementary psychology classes; and a few were obtained from the social psychology class. Particular care was taken to eliminate all *S*s who had had any experience with the rotary pursuit test at any time. All of the *S*s used were then 'naive' as to the experimental setup and procedure.

Procedure

The *S*s were tested one at a time. Modified AAF instructions (see Buxton and Spence, 1) were administered to all. Every *S* received 10 learning trials, each of which consisted of 50 sec. of work and was separated from the next trial by a 10 sec. rest period. At the end of the tenth trial the *S* was assigned to one of the six experimental groups. Following the original learning session, these groups rested for intervals of 10, 30, 150, 300, 600, or 1200 sec. At the end of the rest period, each *S* was given trials 11 and 12, two 50 sec. test trials, separated by a 10 sec. rest interval. All timing was done with a stopwatch. Each group consisted of 15 *S*s, except for the 10 sec. group which had 18 *S*s. During interpolated rest intervals longer than 30 sec., the *S*s were allowed to smoke, read popular magazines or talk with the *E*. A policy of not discussing the experiment during the rest period was carefully followed.

Results

All 93 *S*s received the same amount of original practice, 10 50-sec. trials on the pursuit rotor. During the early portion of the learning series, the distribution of scores was skewed, with most of them piling up at the low end of the distribution. As learning progressed, however, the distribution tended to become more nearly normal. As a result, we decided to report results in terms of mean scores. The means for the different groups on the tenth trial varied considerably, ranging from a low of 7.43 for the 1200 sec. group to a high of 10.07 for the 600 sec. group. Fortunately, however, the differences among group means are not significant. A simple analysis of variance of the scores for the tenth trial yields an *F*-ratio of 0.715, which does not approach significance. For this reason, the *general mean* of the tenth trial scores has been used as the best available index of final level of performance under the present experimental conditions, and supplies the baseline from which one measure of reminiscence has been computed.

In choosing a measure of reminiscence, perhaps the most important consideration is the selection of a stable index. We have made the assumption that the two reminiscence trials together provide a more reliable estimate of post-rest performance than a single score. Therefore, the reminiscence measures presented here involve the mean of the scores on trials 11 and 12. The two measures chosen were the following: 1. the difference between the mean tenth trial score for all *S*s and the post-rest score for the individual group, and 2. the difference between the group tenth trial score and a post rest score for that group.

In Fig. 1 two measures are plotted as a function of the length of the rest interval. It should be observed that these curves have apparently reached asymptotes, at least by 600 sec. on the rest continuum. This presumably means that, under the present experimental conditions, the amount of reminiscence has very nearly reached a maximum, and that longer rests would produce no further recovery.

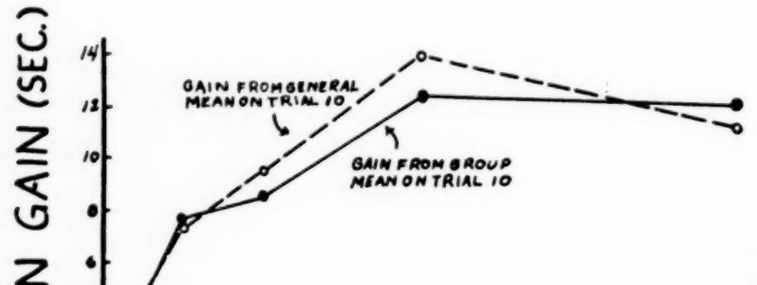

FIG. 1. Reminiscence as a function of length of interpolated rest

The indication that the curves have become asymptotic at this point is supported by the fact that both of our reminiscence measures are actually slightly lower for the 1200 sec. group than they are for the 600 sec. group. Statistically, these differences are not significant: *t*-tests of the mean differences between these points yield *t*-values of 0.19 and 1.23. Neither of these is significant at even the 20 percent level of confidence. On the other hand, analyses of variance performed on the reminiscence measures yield *F*-ratios of 9.24 and 19.14 for the first and second of our gain measures, respectively. These values are both significant beyond the one percent level of confidence. From the statistical analysis as well as from the general shapes of the curves in Fig. 1, the indication seems to be that the amount of reminiscence varies significantly with the length of rest up to 600 sec., beyond which no further difference occurs.

DISCUSSION

As has already been pointed out, the phenomenon of reminiscence is deduced by Hull from the characteristics of an intervening variable, reactive inhibition. The basic properties assigned by Hull to the construct, I_R, are two. First, I_R is a motivational state which inhibits the response being learned in the sense that it produces a tendency to rest. In Hull's terminology, this is expressed by saying that effective reaction potential ($_s\bar{E}_R$) is the difference between simple reaction potential ($_sE_R$) and the total inhibitory potential ($\dot{I}_R$):[1]

$$_s\bar{E}_R = {}_sE_R - \dot{I}_R. \qquad (1)$$

[1] Total inhibitory potential is theoretically made up of two components: I_R and $_sI_R$ (conditioned inhibition). Of these, I_R dissipates; $_sI_R$ does not. As a result, even after rest, the part of $\dot{I}_R$ contributed by $_sI_R$ will still remain and the response measure will be inhibited accordingly. The present experiment was designed to investigate only the hypothetical properties of I_R.

This means that any circumstances which reduce the magnitude of $\dot{I}_R$ will increase ${}_s\bar{E}_R$. Such circumstances will also increase any response measure which varies directly with the magnitude of effective reaction potential, thus producing reminiscence. The time-on-the-target measure used in the present experiment is an index of this type. Since rest is the only variable postulated to reduce inhibition, and since rest has been shown to produce an improvement in performance, our results may be taken as supporting Hull's theoretical statement of the relationship of $\dot{I}_R$ to performance.

The second hypothetical property of I_R is that it dissipates with rest as a simple decay function of time. This latter assumption has been stated more precisely (**2**, p. 301) as follows:

$$t'''I_R = I_R(10^{-qt'''}), \tag{2}$$

where:

$t'''I_R$ = the amount of I_R present at any time, t''',
I_R = the total amount of I_R developed during learning,
10 = the base of the common logarithm,
q = an empirically determined slope constant,
t''' = the time allowed for rest.

In order to show the applicability of this equation to the results of the present experiment, the gain curve based on the tenth trial performance of all *S*s has been used to provide measures of I_R at each point (t''') at which measurements were made in this investigation.

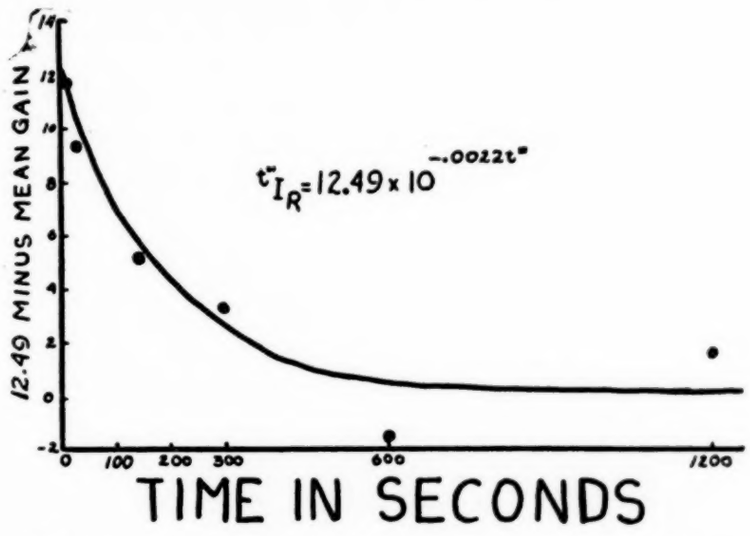

FIG. 2. Decay of reactive inhibition as a function of time

Since maximal gain was found to occur at 600 sec., and since beyond this point apparently no further increase will take place, the gain scores for the 600 sec. and 1200 sec. groups may be taken as indices of the total amount of I_R developed during the 10 learning trials.

The mean of these two gain scores is 12.49 sec. We have used this value as our measure of I_R immediately after the original learning ($t''' = 0$). By subtracting from this value the gain score for every other group, we have obtained a $t'''I_R$ value for each of the six rest intervals. These values have been plotted as the black points in Fig. 2. The smooth curve through these points is a simple decay function with a slope constant of $-.0022$. Using the values of I_R (12.49) and q ($-.0022$) obtained in the present investigation, we may now rewrite Hull's theoretical equation substituting our empirical constants:

$$t'''I_R = 12.49 \cdot 10^{-.0022t'''}. \qquad (3)$$

In Fig. 2, the reader will note this equation appears to fit the data fairly well, at least through the 300 sec. point. Beyond this point, the deviations become somewhat greater. The two groups whose data determined these points happened to be our most discrepant ones in terms of original learning. It is possible, therefore, that these points are more divergent than they might otherwise be, through errors of random sampling.

Summary

1. Six groups of male *Ss* were given ten 50 sec. trials, with a 10 sec. inter-trial interval on a modified Koerth pursuit rotor. After rests of 10, 30, 150, 300, 600, or 1200 sec., two 50 sec. reminiscence trials were given, with the end in view of investigating the relationship between the amount of reminiscence and the length of interpolated rest interval.

2. The results indicate that reminiscence increases as a negatively accelerated function of length of rest and is very close to the asymptote at 600 sec., beyond which longer rests appear to be ineffective in producing greater reminiscence.

3. By inverting the recovery function, a measure of decay of I_R was calculated, and a simple negative growth function was fitted to the points thus obtained.

4. The results of the investigation seem to verify Hull's theoretical formulation of the decay of inhibition as a function of time.

(Manuscript received June 26, 1947)

References

1. Buxton, C. E., and Spence, K. W. *An appraisal of certain tests of pilot aptitude.* Washington, D. C.: CAA, Div. Research, Report No. 64, July, 1946.
2. Hull, C. L. *Principles of behavior.* New York: D. Appleton-Century, 1943.

THE EFFECT OF USING DIFFERENTIAL END BOXES IN A SIMPLE T-MAZE LEARNING SITUATION *

BY M. RAY DENNY

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Introduction

The present study stems from a recent investigation (1) in which it was observed that learning was very rapid when differential end boxes were used in a simple T-maze set up. Twelve reinforcements were found to be adequate for a high level of learning. Since, in the earlier study, the goal box in which the animal received a food reward was unlike the negative end box in which it never received food, it was inferred that the secondary reinforcement acquired by the positive goal box was operating consistently on one side of the maze and not on the other. In other words, we can assume that only a right *or* left turn habit had been built up in each animal. On the other hand, if both end boxes were alike we would theoretically expect the concurrent, though differential, development of opposing habits because of the stimulus generalization of secondary reinforcement [1] from the goal box to the similar negative end box. This means that the *net* response tendency to the correct side will be less after an equal number of trials to each side for a T-maze with similar end boxes than for one with differential end boxes. In line with this analysis, the present study is an attempt to test the hypothesis that learning will be slower with like end boxes than with unlike boxes.

Experimental Procedure

A. Apparatus.—The apparatus, which is more adequately described elsewhere (1), was a simple T-type maze with several special features. It consisted of a starting box and stem, a choice-point section, a pair of arms or delay boxes, and four exchangeable end boxes. The starting box and stem, except for the choice point section, were completely made of wood, as were the sides of the entire maze. The floors and roofs of the delay boxes and choice-point section and the roofs of the end boxes were made of opal flashed glass. This construction largely eliminated extra-maze cues and provided a uniform perceptual field.

The sections of the maze were elevated to permit uniform lighting from below, and the *E* followed the progress of the rat through the enclosed maze by means of the rat's shadow. The like end boxes were the same size as the alleys and painted grey like the inside of the rest of the maze. The unlike end boxes were one in. taller and two in. wider than the alleys, and differentially constructed. The positive goal box was painted white and had a hardware cloth covered floor, while the negative end box was painted black and had a plain beaverboard floor.

* This study was carried out at the Psychological Laboratory, State University of Iowa.

[1] Secondary reinforcement is defined by Hull (3) as the reinforcing property acquired by stimuli which have been closely and consistently associated with a reinforcing state of affairs.

B. Subjects.—The *Ss* run with the unlike end boxes constituted one control group of the experiment previously referred to (1). The *Ss* for the like end boxes, however, were from the same colony of animals, and were run immediately after the completion of the other experiment and under exactly the same conditions, except for the experimental variable. The *Ss* were male and female, albino and hooded rats from the colony of the Department of Psychology of the State University of Iowa.

C. Preliminary training.—The preliminary training schedule was the following: (1) one week of food habituation with each rat receiving eight gm. of Purina Dog Chow per day, (2) three days of preliminary training in a straight alley maze in which each animal received 12 reinforcements in the positive goal box and two non-reinforcements in the negative end box which for the like end box group would be either one of the two grey boxes, (3) the determination of the animal's position preference in the T-maze by the same method as in the earlier study (1). (All *Ss* were trained opposite to the preferred side.)

D. Method in learning series.—Twenty animals were run with unlike end boxes at the end of the alleys and 20 with like end boxes. Typical maze learning conditions prevailed except that the number of trials to each side was equalized for each day. Four trials per day were given with the first two trials of the day permitting free choice of either alley, while the last two were forced so that only the following four patterns of runs were possible: RRLL, LLRR, LRRL, and RLLR. All correct responses were rewarded with two small dog chow pellets (0.20 gm.), and the white goal box was always at the end of the correct alley for each animal run under the unlike end box condition.

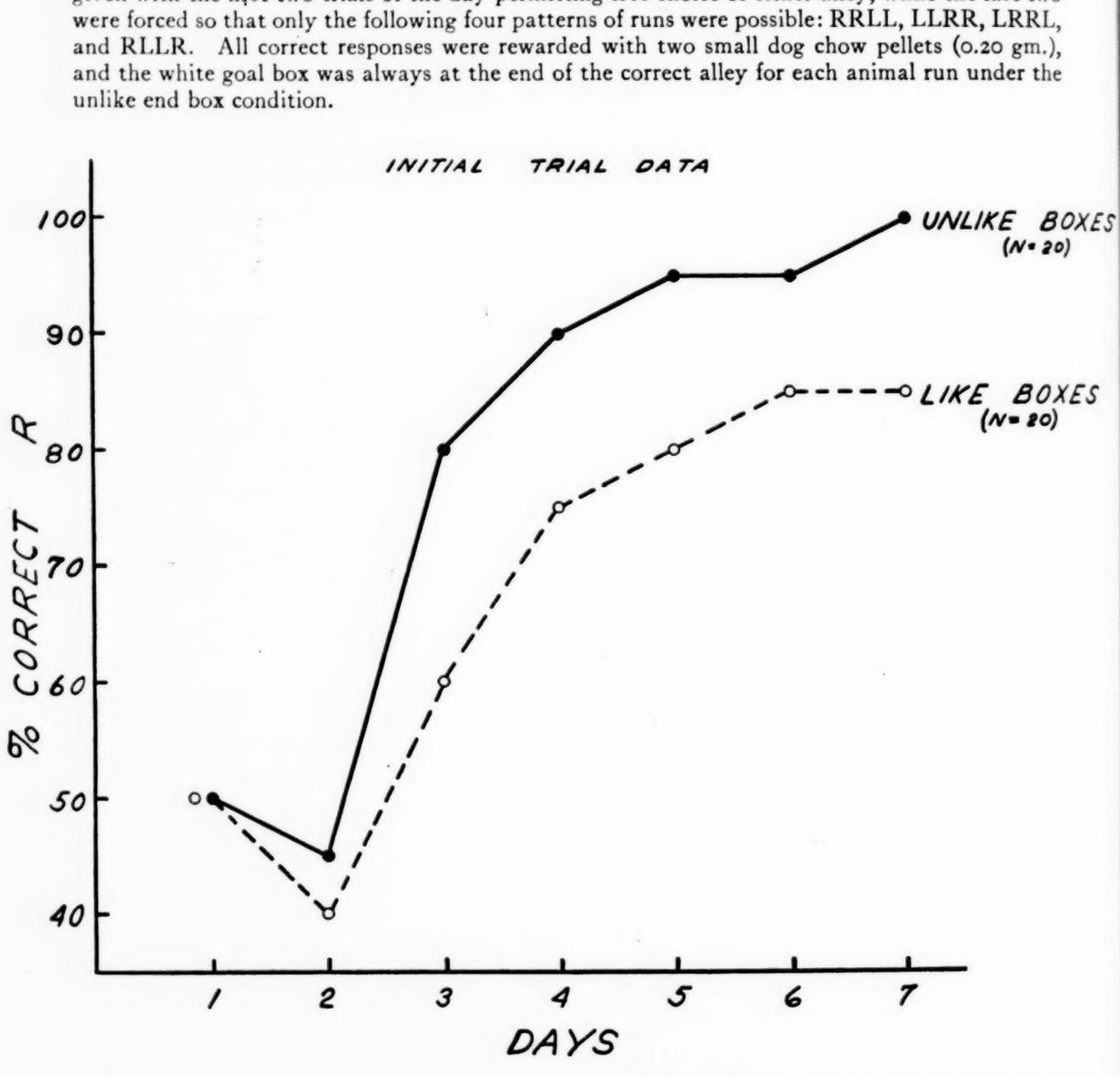

FIG. 1. Learning curves of the like and unlike end box groups as based upon the percent of correct responses on the initial trial of the day

Because of the conditions prevailing in the first investigation, each animal was delayed 15 sec. in either delay box before being allowed to enter the end box, and each animal was retained 20 sec. in the negative end box.

The *S*s were trained only for a period of six days and tested with one free trial on the seventh day because these were the conditions that obtained in the earlier investigation.

The inter-trial interval was approximately 20 min. and a period of 22 hours of food deprivation prevailed.

Results

The data are graphically represented in two ways: (1) using the percent of correct responses on the initial test trial of each day, and (2) using the percent correct for the first two free trials of the day. The first measure is given because it is available from the previous study and shows the groups equally matched on the first learning day. The second measure is the more sensitive and stable in the present study, and gives a slight initial difference in favor of the differential end box group. But this difference is to be expected on the basis of our theoretical analysis, for it is to be remembered that the *S*s of the like end box condition had preliminary training with the grey goal boxes prior to the initial learning trial.

Looking first at the initial trial data presented in Fig. 1, we see that the unlike end box group shows consistently faster learning. The t for the data based on the overall number of correct responses for days 2 to 7 is 2.07, which is significant at the five percent level of confidence (see Table I).

A similar but larger difference between the two groups is shown in Fig. 2. In addition, we see that the learning curve of the like end box group is somewhat positively accelerated while the learning curve of the other group is negatively accelerated.[2] The t based on the

TABLE I

Comparison of the Like and Unlike End Box Groups in Terms of the Mean Number of Correct Responses on the Initial Trials of Each Day for Days 2 to 7

Group	N	No. Correct Responses		Diff.	t	P
		Mean	σ			
Unlike boxes	20	5.05	.98	.85	2.07	<.05>.02
Like boxes	20	4.20	1.50			

[2] It should first be noted that all the curves are positively accelerated at the very beginning of the learning, but that only the learning curve of the like end box group with the two trial measure is still positively accelerated at the end of the experimental session. Assuming that this is a reliable difference, we may possibly account for the continued positive acceleration in the following manner. The animals that go wrong on the initial trial in the like end box group and concomitantly receive secondary reinforcement of this response are more likely to go wrong on the second trial than the ones that go wrong on the initial trial in the unlike end box group and do not receive secondary reinforcement for this response. Such a state of affairs obtains for these *S*s until the correct response tendency which receives the larger of the two habit increments becomes *consistently* stronger than the incorrect. Thus, evidence of learning as measured by the percent of correct responses on the first two trials is at first suppressed and then made more suddenly apparent.

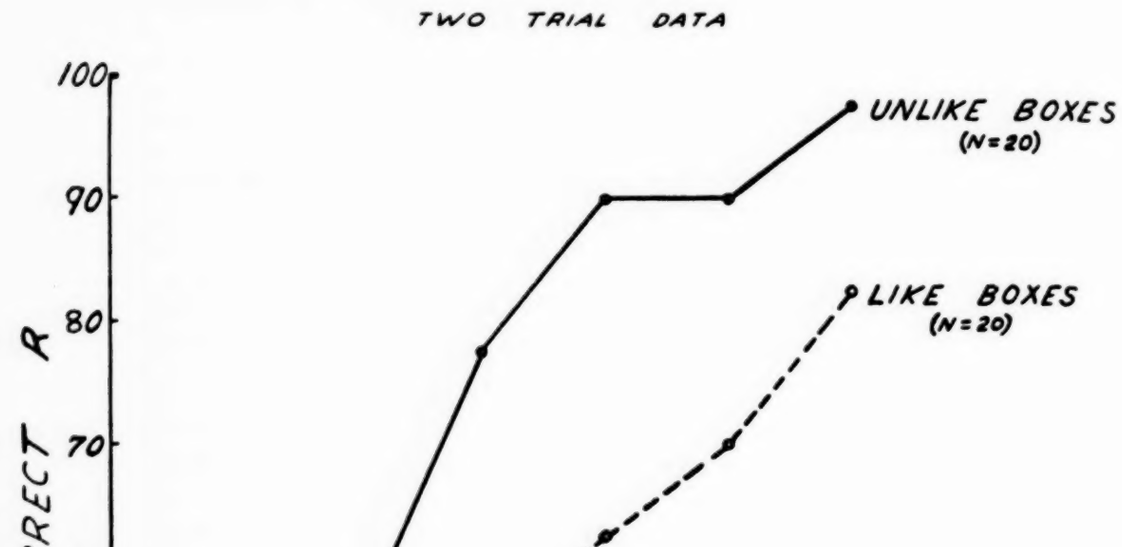

FIG. 2. Learning curves of the like and unlike end box groups as based upon the percent of correct responses of the first two trials of the day

two-trial measure for days 2 to 7 is 4.3, which is significant beyond the one percent level of confidence (see Table II).

The results are summarized in Tables I and II.

TABLE II

COMPARISON OF THE UNLIKE AND LIKE END BOX GROUPS IN TERMS OF THE MEAN NUMBER OF CORRECT RESPONSES ON THE FIRST TWO TRIALS OF EACH DAY FOR DAYS 2 TO 7 *

Group	*N*	No. Correct Responses		Diff.	*t*	*P*
		Mean	σ			
Unlike boxes	20	9.15	1.24	1.95	4.3	<.01
Like boxes	20	7.2	1.50			

* A total of 11 responses.

DISCUSSION

These findings are interpreted as substantiating implications of the principle of secondary reinforcement. It is assumed that in the like end box group the secondary reinforcement generalizes from the

correct goal box to the incorrect end box, providing reinforcement for the rat on wrong responses; while in the unlike end box group stimulus generalization is presumed to be negligible and the animal is consistently reinforced on one side.

The significant aspect of the results is that they were predictable, as were other recent and related findings, purely on the basis of secondary reinforcement theorizing. It is of little consequence that Tolman (4) would also have no difficulty in explaining the results, though it is difficult to see how they would be predictable in Guthrie's theoretical framework (2). Tolman would probably say that learning is faster in a T-maze situation with differential end boxes because of the greater discriminability of the significates. The definite difference between the significates presumably increases the difference between what the rat anticipates at the ends of the right going alley and the left going alley. In short, the more particularized the sign-gestalt-expectation for a food-foodbox significate the faster will be the learning.

It is the writer's opinion that these explanations say the same thing in different words. As far as this area of conceptualization is concerned, the two alternative theories could be made operationally equivalent. The principal legitimate question which might arise in comparing the two behavior theories is: In which system does the logical or postulational structure make for greater predictability?

Summary

The present study was designed to test the hypothesis that learning will be faster in a T-maze situation when the end boxes are different than when they are similar.

The apparatus used was a new type T-maze in which it is possible to control intra- and extra-maze cues. There were four trials per day, and the number of trials to the correct and incorrect side was equalized for each day. Learning of 20 animals run with like end boxes was compared, over a period of seven days, with the learning of 20 animals run with unlike end boxes.

It was found that under these conditions the learning was significantly faster when differential end boxes were employed. The results were interpreted in terms of secondary reinforcement.

(Manuscript received June 27, 1947)

References

1. Denny, M. R. The role of secondary reinforcement in a partial reinforcement learning situation. *J. exp. Psychol.*, 1946, **36**, 373–389.
2. Guthrie, E. R. *The psychology of learning.* New York: Harper and Bros., 1935.
3. Hull, C. L. *Principles of behavior.* New York: D. Appleton-Century Co., 1943.
4. Tolman, E. C. *Purposive behavior in animals and men.* New York: D. Appleton-Century Co., 1932.

AN EXPERIMENTAL STUDY OF WAKING POSTURAL SUGGESTION

BY HAROLD GRIER McCURDY

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Introduction

A technique commonly employed in the investigation of suggestion effects is to observe the change of standing posture under verbal stimulation. Hull (**5, 6**) has described a suitable recording method, and a number of studies have made use of it, with or without modification. Unfortunately, because of numerous differences in the units of measurement adopted, in experimental conditions, and in manner of reporting the results, it is virtually impossible to combine the various experiments into a unified body of information. Thus, for example, it remains a question whether the responses normally are distributed around a single mode, lie between two modes located at the extremes of the range, or trail off to one side. The reputed U-shaped distribution has particularly exercised the ingenuity of several interpreters (**1, 3, 4, 6**).

An especially grave deficiency in the literature appears to be the absence of any standard of comparison. None of the studies seen by this writer have reported on the distribution of responses in a control experiment omitting the verbal stimulation. Without such information, particularly in view of the uncertainty as to the true nature of the distribution when verbal stimulation is applied, the significance of the experimental findings is bound to remain obscure.

Finally, while Hull and the workers reported by him (**6**), and more recently Eysenck and Furneaux (**4**) and Arnold (**1**), as well as others, have contributed to our knowledge of the relation between postural suggestibility and other behavior variables, there is still room for further exploration. Simple as the behavior is, our scientific understanding of it is certainly far from complete.

The present study offers some data on the distribution of the responses in two experimental situations with normal female subjects, and reports on two related variables not previously noted.

Procedure

In the first experimental situation, verbal stimulation was employed. The *S* was required to stand with eyes closed while the *E*, standing in front

and a little to one side, repeated continuously in various ways that the *S* was falling forward. This verbal suggestion was kept up until the *S* had lost her balance or was about to do so (at which point she was checked by a touch against her shoulder) or until a minute had elapsed. A period of 15 or 20 sec. of silence intervened between eye-closure and the beginning of verbal stimulation to permit the *S* to make an initial postural adjustment.

In the second experimental situation, occurring three to four weeks later, the *S* was directed to close her eyes and stand as still as possible. During the minute following these directions, the *E* remained silent.

The *S*s employed were young women, college sophomores, juniors and seniors enrolled in the writer's introductory course in general experimental psychology. Out of the whole class of 84, complete records were obtained on 78 *S*s.

The recording apparatus used was a modification of the postural movement recorder described by Hull (**5, 6**). The chief difference, and not a very significant one, was the employment of a lever system instead of a reducing pulley for scaling down the recorded movement to ⅓ of the original. The *S* stood facing away from the apparatus at a distance of about a yard, and was attached to it by means of a thread hooked to the back of a belt which was strapped about the waist. It was believed that movement at the waist level might be a more reliable index of fundamental postural change than movement at the shoulder. A signal magnet enabled the *E* to mark the beginning and end of an experimental period. The resulting kymograph record consisted of an irregular line showing the *S*'s movement, and the line produced by the signal magnet beneath it, with a horizontal distance of 22 mm. corresponding to a minute of time.

The recorded response was scored by applying a protractor to the shellacked kymograph record and measuring the angle of slope of the movement line between the beginning of the experimental period and its end. In spite of minor irregularities due to the constant small oscillations of the *S*, the slope of the movement line was usually fairly uniform; and by taking the peaks at the beginning and end of the experimental period (one min., or less, as previously explained), as the reference points for making the measurement, it was possible to secure reasonably accurate scores. If, for example, the movement line at the end of a minute (22 mm. on the record) had sloped up to 10 mm. above the base-line established at the beginning of the period, the score was +24 (degrees of angle); if it had sloped down to the same distance below the base-line, the score was −24. It is obvious that a score thus obtained takes into account, in a single figure, the direction of the response, its speed, and its extent. Knowledge of the angle and of the per minute length of the base-line permits one, of course, to obtain the vertical distance on the record for any desired moment by multiplying the base-line distance by the tangent of the angle. It is therefore possible to estimate the distance of the movement crudely for a one-min. period even when the *S* had to be checked from falling within a few seconds after the stimulation was begun.

Results

1. *Distribution of Responses*

Table I summarizes the results from the two experiments. The angle scores listed indicate the mid-points of step intervals of nine degrees. Beside them, for the sake of comparison, are given the estimated distances of the actual movement for one min. in mm., calculated as explained and multiplied by three (since the recorded movement was reduced to ⅓ of the original). The means and standard deviations are stated in terms of the angle score.

TABLE I

Distributions of Body Sway Scores for 78 College Women in Two Different Experimental Situations

Time = one min.

Midpoint Scores (Degrees of Angle)	Estimated Movement (MM.)	Frequencies	
		Suggestion	Non-Suggestion
+81	417	3	
+72	203	3	
+63	130	2	
+54	94	5	
+45	66	1	
+36	48	2	
+27	34	1	1
+18	21	9	7
+ 9	11	9	15
0	0	22	41
− 9	11	15	12
−18	21	4	2
−27	34	2	
		N 78 *M* +12.58 *SD* 27.34	*N* 78 *M* + 1.84 *SD* 8.54

It will be seen that 16 of the positive scores and two of the negative ones in the suggestion distribution lie beyond the extremes of the non-suggestion distribution, or, respectively, 20.5 and 2.6 percent. There is clearly a significant difference between the two distributions. It must be noted, however, that in some respects the distributions are alike. Both show a distinct mode centering on zero, and there is a slight skewness in the non-suggestion distribution corresponding to the larger one found in the suggestion distribution. Whether the skewness in the non-suggestion distribution is due to a natural forward inclination of the human body, or to some other cause, is not certain. That there is some relationship between the two distributions seems to be indicated by a correlation coefficient of .24, which for this number of observations has a *P*-value between .05 and .02.

A slight dip in the distribution of the suggestion scores will be noticed between 18 and 54. The number of observations is insufficient to establish this as a significant fact, but, since other studies have reported similar breaks in the distribution, it may be. At any rate, it is worth considering that somewhere in this region of the scores the swaying *S* reaches a critical point of balance. If a correction for the differing heights of the *S*s had been made, it is possible that the dip would have been more strikingly shown. Certainly, the existence of a critical point of balance might very well produce some kind of break in the distribution.

2. *Related Variables*

Among several variables investigated, two were found which showed significant correlation with the suggestion scores and which have not appeared previously in the literature, so far as the writer knows. These were the reported frequency of dreaming and a poorly understood complex of causes related to the order in which the *S*s presented themselves for the experiment. The respective correlation coefficients were .34 and .45, both lying well beyond the one percent level of significance.

Records had been obtained previously from the 78 *S*s (plus four others) concerning the frequency of their dreaming. The *S*s noted down each morning for a week whether or not they had dreamed during the night. The first set of records was obtained about a month before the suggestion experiment. Two weeks later another sample of dream frequency extending over a week's period was obtained by the same method. The maximum possible score for the two weeks combined was 14. The records revealed a range for the two weeks of 0 to 14, with two modes, one at 6, the other at 14. Taking the samples for the two weeks separately and correlating them yielded a coefficient for the 82 reporters of .78. Inasmuch as the two samples were taken two weeks apart under somewhat different environmental conditions (the beginning of a semester as contrasted with the semester fully under way), it seems a reasonable assumption that frequency of dreaming (which means, of course, the frequency with which dreaming is reported) has some stability as a personality trait.

To appreciate the meaning of the other correlation figure it is necessary to know that the suggestion experiment took place on four successive days, when the *S*s, in groups of around 20, were engaged with other work in a room adjoining the experimental room. The *S*s came into the experimental room one at a time, and after the brief experimental test returned to the room where other members of the group were at work or simply waiting. This arrangement resulted

in a certain amount of discussion of the experiment, perhaps some eavesdropping, laughter and teasing, and other social interchange within the group. For some of the *Ss* the experiment assumed the character of a challenge which had to be reported back to the group. For all *Ss* coming in after the first there must also have been a considerable loss of novelty. Perhaps the total effect of the arrangement described might be somewhat inadequately summed up as a decrease of general excitement with the passage of time. For the purposes of the correlation the measure used, whether it represented decrease of excitement or something entirely different, was simply the order of presentation of the *Ss*. Thus, the first in each experimental group was given the number 1, the second the number 2, and so on through the list. Treating 1 as the highest score, 2 the next, and so on, the positive correlation mentioned, of .45, was found between this measure and the suggestion scores.

In order to get some estimate of the degree of interaction between the two factors in the production of the suggestion scores, partial *r*'s were computed. The figure for frequency of dreaming, with order of presentation held constant, was .47; for order of presentation, with frequency of dreaming held constant, the figure was .55. The multiple correlation coefficient, representing the dependence of the suggestion scores on both factors together, was .66. The contribution of these two factors to the total variance of the suggestion scores was thus 44 percent.

Discussion

Because of the lack of uniformity in collecting and reporting data in this field of investigation, it is not possible to bring the present study into strict conjunction with others. Nevertheless, the opinion may be ventured in regard to the distribution of responses in waking postural suggestion of this type that the data of the study harmonize quite well with the results obtained by Berreman and Hilgard (**2**), and better with the results obtained by Williams and by Landis than with those obtained by Life (**6**); and that there is little evidence here for the U-shaped distribution reported by Eysenck (**4**) and others. Eysenck regards his own U-shaped distribution as a statistical artefact dependent upon his method of measurement; but insofar as there may be a real tendency toward such distributions, the present study hints at the possibility that some critical point, such as that between just succeeding in remaining erect and just failing to do so, may be a determining factor. Incidentally, it is not clear to the writer whether Eysenck's method of scoring, or Life's, allowed for negative values.

That the postural behavior of *Ss* may be significantly altered by verbal suggestion is demonstrated here by comparing two experi-

mental situations differing primarily in the presence or absence of such suggestion; but it is also demonstrated that the form of the suggestion distribution does not differ totally from the form of the non-suggestion one. Furthermore, the correlation coefficient of .24 between the two sets of scores argues faintly for the supposition, supported also by the similarity of the distribution curves, that in the case of some *S*s the verbal suggestion may work by slightly reinforcing a movement tendency already present, so as to exaggerate a normal backward or forward sway. In regard to this point, it is unfortunate that the non-suggestion experiment did not precede the other. From the data in hand it cannot be decided how much of the correlation obtained was due to a carry-over from the suggestion experiment occurring three or four weeks earlier.

Arnold (1) has recently endeavored to support the old theory of ideo-motor action as a sufficient explanation for suggestion effects. Possibly the relationship reported here between frequency of dreaming and suggestibility might be taken as further evidence for that point of view. Vividness of imagery, according to Arnold, is an important determinant of the overt behavior observed in suggestion experiments. Reported frequency of dreaming, however, is not a reliable index of the capacity for vivid dream imagery. It is more likely an index of the degree to which a person is aware of all his psychic processes. The following case is illustrative. One *S*, who had reported four dreams only for the two-week survey and whose suggestibility score was zero, came to the writer for numerous therapeutic interviews. Under the proper encouragement she was able to report many and very vivid dreams. At first, however, she had difficulty in doing so, and there continued to be frequent occasions on which important segments of her dreams temporarily eluded her memory. This difficulty in remembering her dreams was allied with a general forgetfulness of all sorts of emotion-laden experiences. It was as if her field of consciousness were sharply restricted and broken up into fragments by numerous amnesic gaps. This is merely a single case, and the writer realizes how unsafe it is to generalize from one to all; but the possible implications are worth considering.

As to the meaning of the correlation found between the suggestion scores and the order of presentation for the experiment, the minimum conclusion would seem to be that an *S* entering a laboratory is bringing there various residual influences from outside (e.g., the social group) which it is unwise for the experimenter to ignore.

Summary

1. Using a modification of Hull's Postural Movement Recorder, and scoring the responses by an angular measurement which takes

into account direction, speed, and extent of the movement, the postural behavior of 78 normal female *Ss* was investigated in two experimental situations: (a) a *suggestion* situation, in which each *S* was required to stand with eyes closed while the *E* repeated in various ways that she was falling forward, continuing for one minute or until the *S* began to lose her balance; and (b) a *non-suggestion* situation, in which the *S*, after being instructed to stand as still as possible, stood with eyes closed for one min. during which the *E* remained silent.

2. The two distributions obtained under these experimental conditions were compared, and it was shown that, while the range of the suggestion scores is definitely greater than that of the non-suggestion scores and mainly in the direction expected on the hypothesis of suggestibility, the two distributions have certain similarities. In both cases, there is the same direction of skewness, and the scores are distributed on either side of a single mode standing at zero.

3. Correlations found were: between the suggestion and the non-suggestion scores, .24 (P = .05 to .02); between suggestion scores and frequency of reported dreaming, .34 (P less than .01); and between suggestion scores and order of presentation for the experiment, .45 (P less than .01). The amount of variance in the suggestion scores accounted for by the latter two variables was found to be 44 percent.

4. Reference was made in the discussion to the difficulty of combining results from the various reports in the literature dealing with this subject, because of the inconsistency and incompleteness of the reports. It is to be hoped that Hull's simple and valuable test of suggestibility will be more fully explored by workers having an opportunity to deal with large normal populations. The present study has attempted to contribute to the standardization of this kind of investigation.

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References

1. Arnold, M. B. On the mechanism of suggestion and hypnosis. *J. abnorm. soc. Psychol.*, 1946, **41**, 107–128.
2. Berreman, J. V., & Hilgard, E. R. The effects of personal heterosuggestion and two forms of autosuggestion upon postural movement. *J. soc. Psychol.*, 1936, **7**, 289–300.
3. Bird, C. *Social psychology*. New York: Appleton-Century, 1940.
4. Eysenck, H. J., & Furneaux, W. D. Primary and secondary suggestibility: an experimental and statistical study. *J. exp. Psychol.*, 1945, **35**, 485–503.
5. Hull, C. L. Quantitative methods of investigating waking suggestion. *J. abnorm. soc. Psychol.*, 1929, **24**, 153–169.
6. Hull, C. L. *Hypnosis and suggestibility*. New York: Appleton Century, 1933.

MOTOR EFFECTS OF STRONG AUDITORY STIMULI

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The effects of stimuli to the sense organs are commonly traced through the receptors, along the different fibers into the spinal cord or brain nuclei, and from there to certain regions of the cerebrum. The course of events then ensuing is in general a matter of inference and speculation. Presumably their nature and direction are influenced by the structure and prior excitation of the region; presumably, also, they influence in turn excitations which enter the organism at a later time. Where there is no immediate visible response the results of sensory stimulation are supposed by some to terminate in the neural tissue after producing, probably, some modification therein. 'Implicit' responses in the soma, on the other hand, have been thought by some to follow upon all sorts of stimulation and in one way or another to set the stage for the next 'overt' action.

Many small scale somatic activities have, of course, been observed. Most studies of these have been in search of activities in progress while the individual was carrying out an assigned task, a task which resulted in eventual overt response (such as problem solving: **2**, **4**) or which remained implicit (such as imaging: **9**, **11**). But if the theory of implicit somatic reactions is generalized one should also expect them to be found when the individual is, to outside observation, quite passive and merely receiving stimulation. Such a case would be one in which the individual is instructed to do nothing upon reception of a stimulus. The stimulus would be of a sort, preferably, that has some effect on the individual which could be demonstrated by later report. Under such conditions it is conceivable that the energy disturbances of the receiving process, which might be of maximal intensity, are blocked and dissipated somewhere in the cerebral cortex, for instance. On the other hand, it is possible that they continue to follow the response arc and dissipate themselves in peripheral actions. If peripheral effects could be demonstrated under those conditions they would be of interest, of course. But their significance would be much greater if it could be demonstrated further that they bear some relation to (1) the character of the stimulus employed, (2) the prior state of the organism, or (3) any subsequent (or possibly concomitant) response of the individual. For if there are such relations, we should be in the way of deciding whether the organism typically makes use of a series of peripheral (sensory)—central—peripheral

(motor) circuits, or whether, in many important instances, the final limb of the traditional arc is absent or unimportant. Further, should there be peripheral responses with significant relationships we should be provided with a powerful tool of investigation, since it would then be possible to use them as indicators of the processes which intervene between a stimulus and its overt response which may not occur for some little time. By this means, there might be a direct attack made upon the 'intervening processes' so frequently discussed.[1]

The experiments here reported are the beginning of an investigation of the existence and relationships of motor components of responses usually termed sensory. The stimuli selected for the test were auditory, since they are convenient to administer and perhaps simpler in that pre-stimulus fixation need not be considered as it would need to be for visual stimuli. The stimuli were of high intensity level, for this seemed desirable in a first study.

It is not entirely correct, of course, to imply that implicit responses to auditory stimuli are altogether unknown.

Autonomic responses, particularly the galvanic skin response, are easy to demonstrate with auditory stimuli under the conditions mentioned. In the case of the GSR anyway, there are, further, certain relationships to stimulus intensity (**8**). Loud sounds produce a variety of responses, mediated by the central as well as the autonomic divisions (1). In general, however, the known responses fail to correspond with expected psychological effects in two ways: (1) With the exception of the skeletal muscle response ('startle response') they occur so late after the stimulus that they could not intervene between the stimulus and many final overt responses. (2) All these responses diminish with adaptation far more readily than final overt responses do. 'Annoyance,' for example, may well be increasing and discrimination improving, while these responses are falling off.

The speed with which the skeletal muscles may respond following a stimulus suggests their responses as a possible field of study for the problem in hand. Accordingly in the present experiments the recording made was of skeletal muscle responses, using the action potential technique. The special object of Experiment A was to discover what response occurred and how it might be related to stimulus intensity. Experiment B was designed to discover whether a pre-existing pattern of muscle tension would influence the response.

Procedure

Two experimental groups were used; six *S*s for Experiment A and 24 for Experiment B. For both experiments each *S* lay on his back on a cot in a

[1] Failing this method there would remain, of course, the brain potentials to be used for the purpose in the normal organism.

shielded room. 'Active' electrodes (five mm. discs, with electrode jelly) were attached to the crest of extensor muscles on the dorsal surface of both forearms (2–3 in. below the elbow). The 'reference' electrodes, consisting of large thick felt pads ($2 \times 6 \times \frac{1}{2}$ in.), were placed on the upper arms. (These would attenuate to a high degree any potentials from this location.) Two recording systems with adjustable gain with inputs ungrounded as previously described (**6**) were used. These systems fed into two cathode ray oscilloscopes and the track of their spots was photographed with a moving film camera.

*S*s were instructed that there would be a five min. relaxation period which would be followed by loud sounds at intervals, and that *S* was to remain in the same position and do nothing in response to the sounds. In cases where the initial tension level was high during a 'normal' situation, suggestions were made to *S* (over a communication system) for further relaxation during the five min. rest period.

Sound stimuli of 500 cycles were generated by a beat frequency oscillator which fed into a power amplifier which in turn activated a loud speaker mounted in the wall of the shielded room. The intensity of the sound was controlled by switches which inserted fixed resistors into the oscillator-amplifier connection. The three intensities used in the experiments were measured with a General Radio sound level meter, the pick-up being placed in the position of *S*s head. The readings obtained were 100, 102, and 103 db. It is doubtful, however, whether these figures are very significant in this case. The wave pattern when inspected on an oscilloscope shunted across the speaker showed that for all three stimuli the amplifier was overloaded and was cutting off the tops of the waves or, in other words, introducing a series of higher harmonics. The amplitudes of the principal wave for the three stimuli bore about the ratios indicated by the meter readings, but in the presence of such harmonics sound level meter readings are likely to be in error (**1**).

Measuring by another method, a relatively pure tone of the same frequency was matched for loudness with the stimulus tones by an observer, and the intensity of the matched pure tone was then read on the sound level meter. By such means the three stimuli intensities were measured as 90, 95, and 99 db. (averages of three *O*s). This method (**1**) uses the human ear to overcome the defects of the meter in this kind of sound measurement, and the results may be taken as most representative of the stimulus values. Differences between the three sounds were obviously far greater than threshold differences. All stimuli, of course, were quite loud.

The duration of the stimuli was controlled by means of an electronic timer, so arranged as to turn on the stimulus at the throw of a switch and turn it off automatically after a determined interval (four sec. for Experiment A, two sec. for B). The timer also activated the argon flash bulb used as a stimulus signal, and an electric stop clock for checking the duration setting.

In Experiment A, *S*s lay with hands resting palm downward beside them on the cot at all times. Three stimuli of each intensity were delivered in mixed order, with two-min. intervals between stimuli. The order was

varied for different *S*s so that each stimulus occupied each serial position an equal number of times. (See Table I.) In Experiment B the highest stimulus intensity was used throughout. For one group of three stimuli *S* kept his hands in the position used in Experiment A. For another group tension was induced in the right arm prior to stimulation, and for another in the left. The tension was induced by having *S* lay the hand in question on the abdomen or, if that failed to induce a clear increase (as seen on the oscilloscope), *S* was required to hold a small box in the air over his abdomen. The order of these three treatments (rest, right tension, left tension) was varied from *S* to *S* so that each occurred an equal number of times in each sequential position.

The recording camera was started a few sec. before the onset of the stimulus and stopped shortly after its end. Each record was then marked off into intervals of 0.1 sec., beginning at the onset of the stimulus, going back .2 sec. and forward through the stimulus duration. In Experiment A only sample intervals were marked off at definite times during the last two sec. of the stimulus duration. In Experiment B the two intervals immediately after the stimulus were marked off; in Experiment A an interval of 0.7 sec. after the end of the stimulus was used also. The records were then projected on to a wall scale by a Delineascope and the distance between the longest positive and the longest negative peak in each tenth of a sec. was recorded, making altogether some 14,000 readings. The next step was to convert these to microvolts by reference to a calibration photograph of a standard 100 cycle 12 microvolt wave supplied to the recording systems at the close of each *S*'s run. The necessary group and sub-group means, as indicated below, were then computed for readings taken at corresponding times with reference to the onset of the stimulus.

Results

Experiment A.—Such averages are shown in Fig. 1 in their proper sequence for tensions following the three stimulus intensities and for the two arms. The first effect of the stimulus, seen most clearly with the 'loud' stimuli in the right arm, begins about 0.1 sec. after the onset of the stimulus and reaches its peak about 0.1 sec. later. Thereupon it dies out more slowly over the next 0.5 sec., though it does not reach the pre-stimulus level even at that time. This response is clearly the one described in an earlier study (4) and for convenience may be called the a-response. In the left arm the a-response to the 'loud' stimulus is smaller, and with the less intense stimuli, absent or doubtful. Following this wave [2] is another response (or second wave of the first) which has not previously been described in records of this kind. This it will be convenient to call the b-response. In response to the strongest stimulus this b-response seems to begin at about 0.8 sec. after the onset of the stimulus. The response curves

[2] 'Wave' as used here refers, of course, to the appearance in the graph under discussion. In the original records this is seen as a series of spikes of varying heights.

for the other stimuli, however, suggest that the inflection of the curve at this point may be deceptive. When the a-response is small the inflection point comes much earlier. The inference is that the b-response actually begins to develop at a very early point, perhaps as early as the beginning of the a-response, and that the a-response, or much of it, is superimposed on the early stages of the b-response. The b-response, then, is slow in developing with the average reaching its greatest value at something like a second after the onset of the stimulus. The duration of the maximum is apparently a little short of one sec.; then there is a decay, rapid at first and then slow. At the last measurement, a half-sec. after the end of the stimulus, four and a half sec. after its onset the level of tension is still above that of the pre-stimulus period. The amplitude of the second response, as shown by these group averages, is here comparable to that of the a-response to the strongest stimulus. These observations on the duration and amplitude of the average responses do not necessarily apply to single responses, since higher individual maxima occurring at varying times might be distributed so as to produce such a trend in averages. Further analysis will discover the characteristics of the two responses.

The a-response. The earlier study referred to (4), based on readings from one arm only, reported that the a-response adapts rather quickly with repeated stimulation, and remains adapted to a considerable degree over a 24 hour period, that it is greater with a greater level of pre-existing tension, but that it is unrelated to *S*s intention to inhibit the response or reports of relaxation. The present study offers opportunity to check some of these findings and add to them. The existence of the response is clear enough in the response to the strongest stimulus in the new data, but its relation to stimulus intensity and repetition needs some further analysis. For this purpose a measure of the response was taken as the difference between either reading 3, 4, or 5, whichever was greatest, and the rest level at reading 2, just before the onset of the stimulus. (The calculation was made for each response. Such measures will be somewhat inflated by the method of selection, but it seems that they may properly be compared with each other.) Tables I and II show the resulting averages. In these the numerals I, II, and III refer to the first, second, and last thirds of this experimental series, in each of which one stimulus of each intensity was administered to each *S*. Stimulus intensities are designated Weak, Medium, and Strong. (The terms are relative, of course.) There are three entries in each cell, which are the averages for *S*s who received the indicated treatment first, second, and third, respectively. These tables were then treated by analysis of variance, estimates of variance being based on variance between stimuli, vari-

TABLE I

THE A-RESPONSE IN THE RIGHT ARM MICROVOLTS INCREMENT—EXPERIMENT A

Parts of Series	I	II	III	Mean
Weak S	A 2.8 B 2.4 C .8	C .8 A .4 B 1.2	B 1.2 C 2.0 A .4	1.3
Medium S	B 2.0 C 2.0 A 2.0	A .4 B .8 C 2.4	C 0 A −1.2 B .4	1.4
Strong S	C 9.2 A 2.0 B 3.6	B .8 C .4 A .8	A 2.4 B .4 C 4.4	2.5
Mean	3.0	.9	1.1	1.7

TABLE II

THE A-RESPONSE IN THE LEFT ARM MICROVOLTS INCREMENT—EXPERIMENT A

Parts of Series	I	II	III	Mean
Weak S	A 1.6 B 2.0 C .8	C .4 A .4 B .8	B 1.2 C .4 A −.4	.8
Medium S	B .4 C 1.2 A 2.8	A 0 B 1.6 C 1.2	C .4 A −.8 B −.8	.7
Strong S	C 12.4 A 1.6 B 1.2	B .4 C 0 A −.4	A .4 B .4 C 2.0	2.0
Mean	2.7	.5	.3	1.1

ance between thirds of the series (adaptation effect), the variance between positions within the thirds, and the residual variance. For the right arm both stimulus intensity effect and adaptation effect are significant at better than the one percent level when tested against the residual variance. For the left the adaptation effect is significant at the five percent level and the stimulus intensity effect fails to show any substantial significance.[3]

If the averages for the columns and rows are compared with their standard errors (derived from the remainder variance) it is found that only those for the loud stimulus and for the first third differ significantly from zero. Further, when the loud stimulus was presented in the first position, it produced an especially large response. Evidently the response approaches zero quite rapidly as the stimulus strength falls off and as the stimulus is repeated.

[3] This procedure, of course, simply tests the hypothesis that the effects are attributable to uncontrolled variations in a series of data like the present.

The b-response. The first problem for the b-response is to provide a statistical test of its existence. To measure it for this purpose a single reading was chosen (No. 14, 1.2 sec. after the onset of the stimulus) and from it the 'resting' level at reading No. 2 was subtracted. This treatment was given to each response and the resulting averages are presented in Tables III and IV, constructed on the same plan as Tables I and II. Analysis of variance with respect to the same factors as used before was carried out to arrive at standard errors of the general means. For the right arm this is .32 and for the left .24. When the means are compared with these, they are seen to be highly significant. The b-response, in other words, cannot be explained as uncontrolled variation in the series.

To test the effects of the experimental conditions upon the response, a different measure was needed, and a measure like that used for the a-response was derived by selecting the maximum of each

TABLE III

THE B-RESPONSE IN THE RIGHT ARM MICROVOLTS INCREMENT—EXPERIMENT A

Parts of Series	I	II	III	Mean
Weak S	A 1.6 B .8 C 0	C .4 A 3.2 B 1.6	B .4 C −2.0 A 3.2	1.0
Medium S	B 2.4 C 1.8 A −.4	A 2.4 B −2.4 C 1.2	C .4 A .4 B 1.2	.7
Strong S	C −.4 A 3.6 B .4	B 0 C 1.2 A 2.0	A 4.4 B .4 C .4	1.3
Mean	1.0	1.1	.9	1.0

TABLE IV

THE B-RESPONSE IN THE LEFT ARM MICROVOLTS INCREMENT—EXPERIMENT A

Parts of Series	I	II	III	Mean
Weak S	A .8 B .8 C 1.6	C .4 A 3.2 B .4	B .8 C −.8 A .4	.8
Medium S	B .4 C .4 A .4	A 0 B .4 C −.4	C −.4 A 2.0 B 0	.3
Strong S	C .4 A 2.4 B 1.2	B −.4 C −.4 A 2.8	A 3.2 B 0 C −.4	.9
Mean	.9	.7	.6	.7

response between the 12th and 20th readings (1.0 to 1.8 sec. after stimulus onset) and subtracting reading 2 from it. Since the resulting tables are very similar to III and IV except for somewhat larger values they are not here reproduced. The F ratios, as inspection suggests, do not even approach significance. Within the ranges here used evidently stimulus intensity and repetition have little or no effect on the size of the b-response.

It is clear that the a and b waves (more exactly, the first and second parts of the response curve) behave quite differently as functions of the stimulus. The first is evoked by very strong stimuli, and

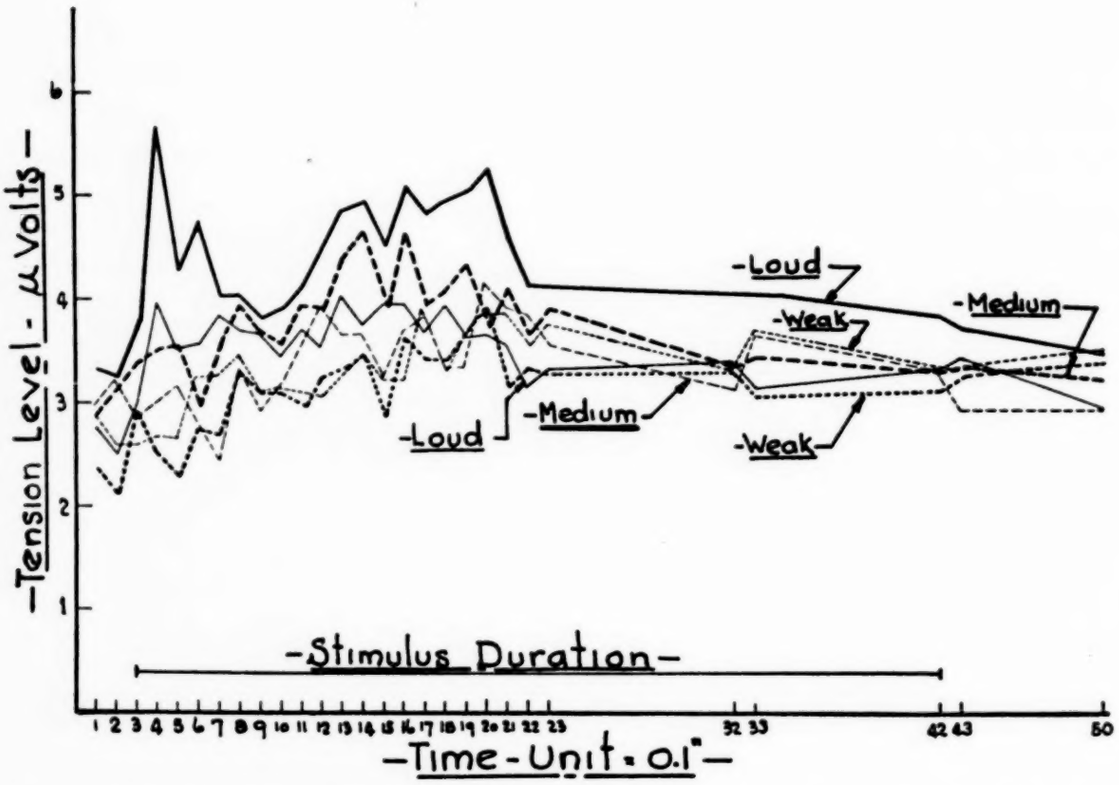

FIG. 1. Experiment A. Mean tension level as affected by the auditory stimuli. Light lines show left arm and heavy lines right arm tension.

approaches zero as the stimulus falls below 100 db.; it adapts so rapidly as to approximate zero with only three or four stimulations two min. apart. The second is impervious to stimulus variation of the sort here used. It is desirable, then, to speak of the two as separate, rather independent, responses with different time and stimulus relations. This is not to say that a response curve will always show two distinct waves. In fact the majority of the curves in Fig. 1 give clear indication of only one, the b-response. The interpretation is rather that the first and second parts of the response have different functional relationships, and hence might appear in all sorts of combinations, given the proper conditions. Even with large responses in

both parts, however, distinct waves might not appear, for large response might be long and so leave no intervening low point.

Experiment B.—The trend of results for the 24 *Ss* used in this experiment is shown by the six lines in Fig. 2a, b, c, which represent the average tension level in each tenth of a sec. through the critical

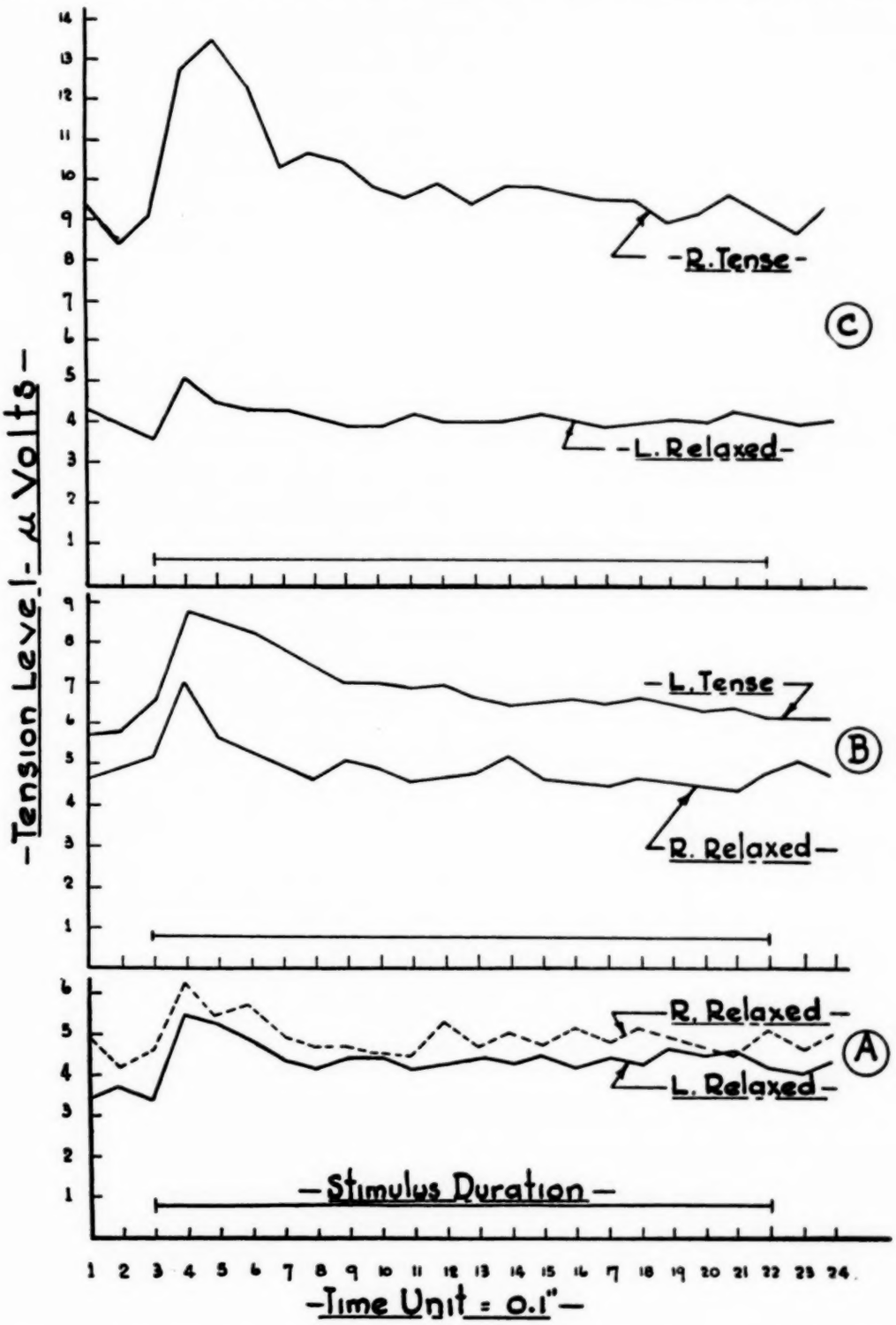

FIG. 2. Experiment B. Mean tension level as affected by auditory stimulus under the three experimental conditions

period. Inspection of these curves suggests certain effects, some of which may be tested by further analysis.

1. The a-response is evident under all conditions, with its maximum usually at reading 4 (0.1 to 0.2 sec. after the stimulus onset).

2. There is a wave corresponding to the b-response only under condition of relaxation for both arms, and even there it is small enough to make its significance need testing.

3. Under the right relax-left relax condition the tension level in the right arm begins and stays at a higher level than that in the left.

4. Either arm with artificially induced tension stays at a higher tension level than the other through the stimulus period. It is apparently easier to induce a tension difference in favor of the right arm than in favor of the left. (The opposite was true of the two left-handed *Ss*.)

5. The a-response, at least, appears to be related rather intimately to the initial tension level.

The a-response. For further analysis the same measure of the a-response was used as in Experiment A, i.e., the difference between the peak (reading 3, 4, or 5) and the pre-stimulus level for each con-

TABLE V

THE A-RESPONSE IN THE RIGHT ARM MICROVOLTS INCREMENT—EXPERIMENT B

Parts of Series	I	II	III	Mean
Both Arms Relaxed	A 6.4 B 1.4	C 3.2 E 4.2	D 2.8 F 1.7	3.3
Right Relaxed Left Tense	C 6.0 D 4.9	B .8 F 2.3	A 2.1 E 1.6	3.0
Right Tense Left Relaxed	E 11.7 F 13.8	A 7.2 D 10.2	B 3.6 C 5.2	8.4
Mean	7.2	4.7	2.9	4.9

TABLE VI

THE A-RESPONSE IN THE LEFT ARM MICROVOLTS INCREMENT—EXPERIMENT B

Parts of Series	I	II	III	Mean
Both Arms Relaxed	A 6.2 B 4.5	C 2.9 E 1.1	D 2.4 F 1.2	3.1
Right Relaxed Left Tense	C 5.0 D 9.4	B 2.4 F 3.7	A 5.9 E 2.2	4.7
Right Tense Left Relaxed	E 2.6 F 5.0	A .9 D .8	B .5 C 1.6	1.9
Mean	5.5	2.0	2.3	3.2

dition. These figures are shown in Tables V and VI. In these tables, I, II, and III represent as before the first, middle and last thirds of the series (three stimuli each), while the other chief variable is the state of tension or relaxation in the two arms as produced by instruction, in the two arms. The letters within the cells designate groups of *S*s, for each of which one of the six possible orders of procedure was used. Analysis of variance then took account of the following factors:

1. Adaptation
2. Tension conditions produced by instruction
3. Inter-group differences and order of presentation (chiefly the former, no doubt)
4. Remainder

It is possible to compute *F*-ratios on two bases: one may compare the tension and adaptation variance estimates with the estimate from the 'remainder' to evaluate the role of uncontrolled variation or one may compare them with the estimate derived from inter-group differences to evaluate the role of *S* sampling. Computed both ways the ratios are as found in Table VII. If the two sources of error variance are

TABLE VII

RESULTS OF ANALYSES OF VARIANCE OF TABLES V AND VI

	F-ratio (Intra-group) (2–8 d.f.)	Minimum Level of Significance	*F*-ratio (Inter-group) (2–5 d.f.)	Minimum Level of Significance
Right Arm				
Adaptation	4.41	5%	3.01	<5%
Tension	12.45	1%	8.98	5%
Left Arm				
Adaptation	13.88	1%	8.58	5%
Tension	7.78	5%	4.87	<5%

considered together the significance levels are five, one, one, and five percent, respectively.

It seems reasonable to conclude that tension instructions and adaptation produce a significant effect upon the a-response.

The exact course of adaptation of this response can be discovered by a finer breakdown of the averages in Tables V and VI. The responses represented in the first column were subdivided and the average responses of all *S*s to the first, second and third presentations of the stimulus were computed. (Since less change took place in the middle and last thirds of the series further breakdown of them seemed unnecessary.) These calculations give the adaptation curves shown in Fig. 3. The absolute level of these curves is of course affected by the several tension conditions under which the data were taken, but

since the same combination of tension conditions enters at all points, the curves may be taken as fairly representative of the adaptation effect. The decline is sharp: at the ninth presentation the response is about ⅓ its original size. That it is not so rapid as in Experiment A is very likely caused by the shorter duration of each stimulus (here two sec. rather than four).

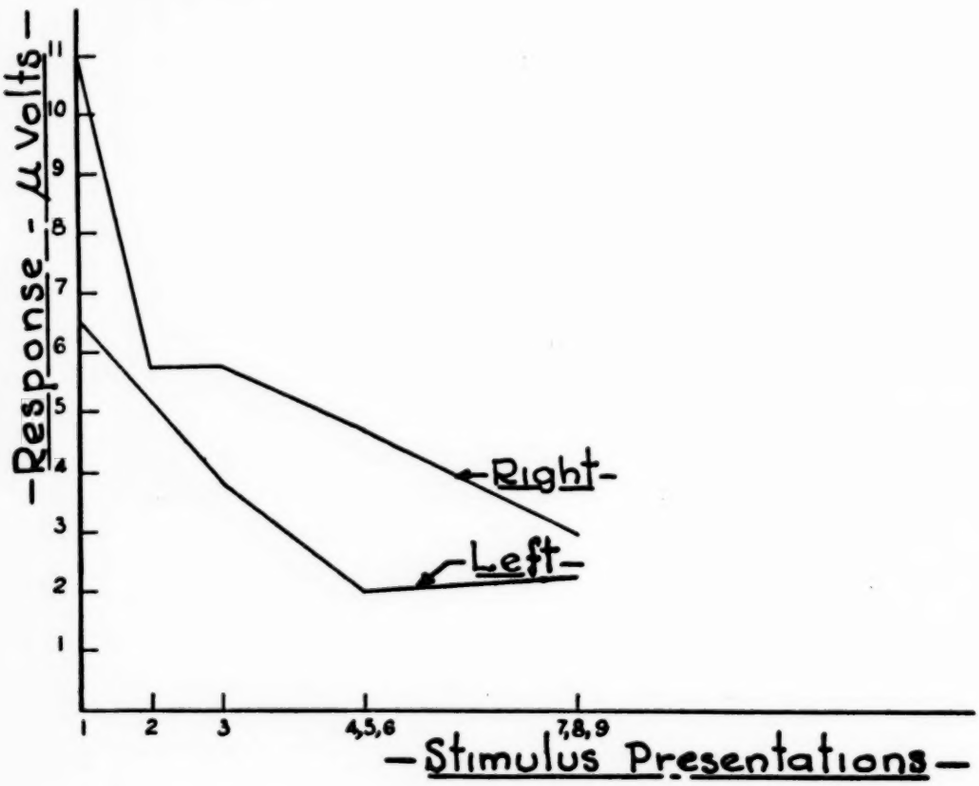

FIG. 3. Experiment B. Mean a-response to successive stimulus presentations

The b-response. Since the presence of the b-response is not obvious in the curves in Fig. 2, the first question logically should be whether it actually exists in this experimental series. It might be absent, or its presence might be obscured by an a-response so long as to merge with it. Tables similar to III and IV were constructed and treated in the same manner as those tables, though with both possible error variances used for evaluating the general means. (Since the tables are very much like VIII and IX, except that the values are smaller, they are not reproduced.) Since three of the resulting ratios exceed the one percent level of significance and the fourth exceeds the five percent level it is proper to recognize the existence of some response at the point concerned. This test of significance simply establishes that the tension level at the designated point is significantly greater than the 'rest' level, and would not in itself warrant the recognition of a second response. In view of the results of Experiment A, however, we may use the term 'b-response,' and examine

whether the results of Experiment A are confirmed in Experiment B, so far as the two develop. (Since it will be shown in the following that the b-response is a function of certain variables, it could also be argued that its existence is thereby implied.)

Tables VIII and IX contain the data for the b-response handled in the same manner as was the a-response in Tables V and VI. The measure here used is the maximum reading between the 12th and

TABLE VIII

THE B-RESPONSE IN THE RIGHT ARM MICROVOLTS INCREMENT—EXPERIMENT B

Parts of Series	I	II	III	Mean
Both Arms Relaxed	A 3.8 B 1.7	C 2.1 E 3.4	D 2.5 F 5.0	3.1
Right Relaxed Left Tense	C 1.3 D 2.2	B 2.4 F 1.4	A 2.2 E 2.3	2.8
Right Tense Left Relaxed	E 5.9 F 5.6	A 3.3 D 5.0	B 5.1 C 4.8	5.0
Mean	3.4	2.9	3.6	3.4

TABLE IX

THE B-RESPONSE IN THE LEFT ARM MICROVOLTS INCREMENT—EXPERIMENT B

Parts of Series	I	II	III	Mean
Both Arms Relaxed	A 6.5 B 3.2	C 1.6 E .5	D 2.2 F 2.3	2.7
Right Relaxed Left Tense	C 2.9 D 2.2	B 2.6 F 4.3	A 5.6 E 1.5	3.2
Right Tense Left Relaxed	E 1.4 F 3.1	A 2.1 D 1.7	B 1.0 C 1.3	1.8
Mean	3.2	2.1	2.3	2.6

20th, minus the second reading, and the purpose here is to examine the effects of tension conditions and of stimuli repetition on the b-response. The resulting *F*-ratios are:

When both sources of error variance are considered together the tension effect for the right arm is practically at the one percent level, and the other levels or significance are unchanged. There is no evidence then for any effect of stimulus repetition on this response. If the averages in the first columns of Tables VIII and IX are separated into their three constituents, and averages are obtained for the first, second, and third presentations, there is some indication of an adaptation effect of small magnitude, which is not, however, statistically significant in the present case.

TABLE X

RESULTS OF ANALYSES OF VARIANCE OF DATA OF TABLES VIII AND IX

	F-ratio (Intra-group) (2–8 d.f.)	Minimum Level of Significance	*F*-ratio (Inter-group) (2–5 d.f.)	Minimum Level of Significance
Right Arm				
Adaptation	.26	<5%	1.11	<5%
Tension	4.65	5%	19.8	1%
Left Arm				
Adaptation	2.24	<5%	.45	<5%
Tension	3.34	<5%	.66	<5%

The results of Experiment A concerning adaptation are therefore confirmed. With the a-response showing adaptation and the b-response little or none in those data, opportunity is offered to check the interpretation that the response curve will show two peaks when the a-response is reduced. Accordingly, response curves like those in Fig. 2 were computed for different stages of adaptation. The a-response should be small under relaxation conditions and after adaptation, and the b-response should appear as a second distinct peak. This is indeed the case: two peaks appear with an interval of approximately rest level tension between them. In other words, because the first and last peaks of the response curves have different determiners it can be understood why the curve will sometimes show a rise only in the first, sometimes only in the second, and sometimes in both.

It is clear, on the other hand, that the several tension states do produce differential effects on the b-response in the right arm. Taken by themselves the *F*-ratios for the tension effect on the left arm indicate that the results could be explained as the operation of error factors. It is also possible, of course, that there is a real effect of tension, though too small to be distinguished from the error factors

TABLE XI

RELATION OF A- AND B-RESPONSES TO IPSILATERAL AND CONTRALATERAL PRE-STIMULUS TENSION. EXPERIMENT B

	Ipsilateral Tension	Contra-lateral Tension	Reciprocal of Contra-lateral Tension	a-Response	Residuals*	b-Response	Residuals*
Right Arm Response	4.4	3.8	.26	3.3	.3	3.1	.5
	4.9	5.8	.17	3.0	−.8	2.8	−.2
	8.1	4.0	.25	8.4	.2	5.0	.0
Left Arm Response	3.8	4.4	.23	3.1	.8	2.7	.5
	5.8	4.9	.21	4.7	−.2	3.4	−.2
	4.0	8.1	.12	1.9	−.6	1.8	−.6

* From regression lines. See text.

by this amount of data. The latter interpretation accords well with facts uncovered in the following section.

The relation to induced tension. The devices used to induce tension were not, of course, equally effective in all the experimental conditions, and it is consequently of interest to examine the quantitative relation between tension level and the responses. In Table XI the two responses are compared with the pre-stimulus tension levels in the ipsilateral and contralateral arms. The response measures used are the maximum already described and the tension level is that at reading 2. Both a- and b-responses show a close relation to the amount of ipsilateral tension. The correlation coefficients are .97 and .95 for the a- and b-responses, respectively. The regression equations are

$$a = 1.39\,I - 3.08$$
$$b = .62\,I - .12$$

where a and b are the two responses, and I the initial ipsilateral tension. These relations being as close as they are, it is surprising to find that the residuals (deviations from the regression line) also show systematic variation. They do, however, show a non-linear inverse relation to the contralateral pre-stimulus tension and a direct linear relation to its reciprocal. (These variables are also shown in Table XI.) The latter relation is measured by a correlation coefficient of .77 for the a-residuals, and .84 for the b-residuals, with the following regression equations:

$$\text{a-residual} = \frac{9.6}{C} - 2.0$$

$$\text{b-residual} = \frac{7.4}{C} - 1.5$$

A combination of the first and second order equations should give the best representation of the relationships of the responses. These combined equations are:

$$a = 1.4\,I + \frac{9.6}{C} - 5.1$$

$$b = .6\,I + \frac{7.4}{C} - 1.6$$

The accuracy with which they predict the results may be seen in Fig. 4.

(The correlation between I and I/C is slightly negative, but too small to be regarded.)

The implication of the foregoing analysis is that both motor responses follow the excitation pattern already in existence at the time

the stimulus is delivered. The response in any one location will depend directly on the prior excitation at that location, but will be slightly inhibited by prior excitation in a contralateral location. The total of responses in both locations considered will vary closely with the total prior excitation, but in non-linear fashion because of the contralateral inhibition effect. In case of unequal prior excitation the geographical pattern of the response will be similar to that of the prior excitation, but will be somewhat more sharply concentrated in one locale, again because of the contralateral inhibitory effect. As would be expected the results of this experiment fulfill these predictions.

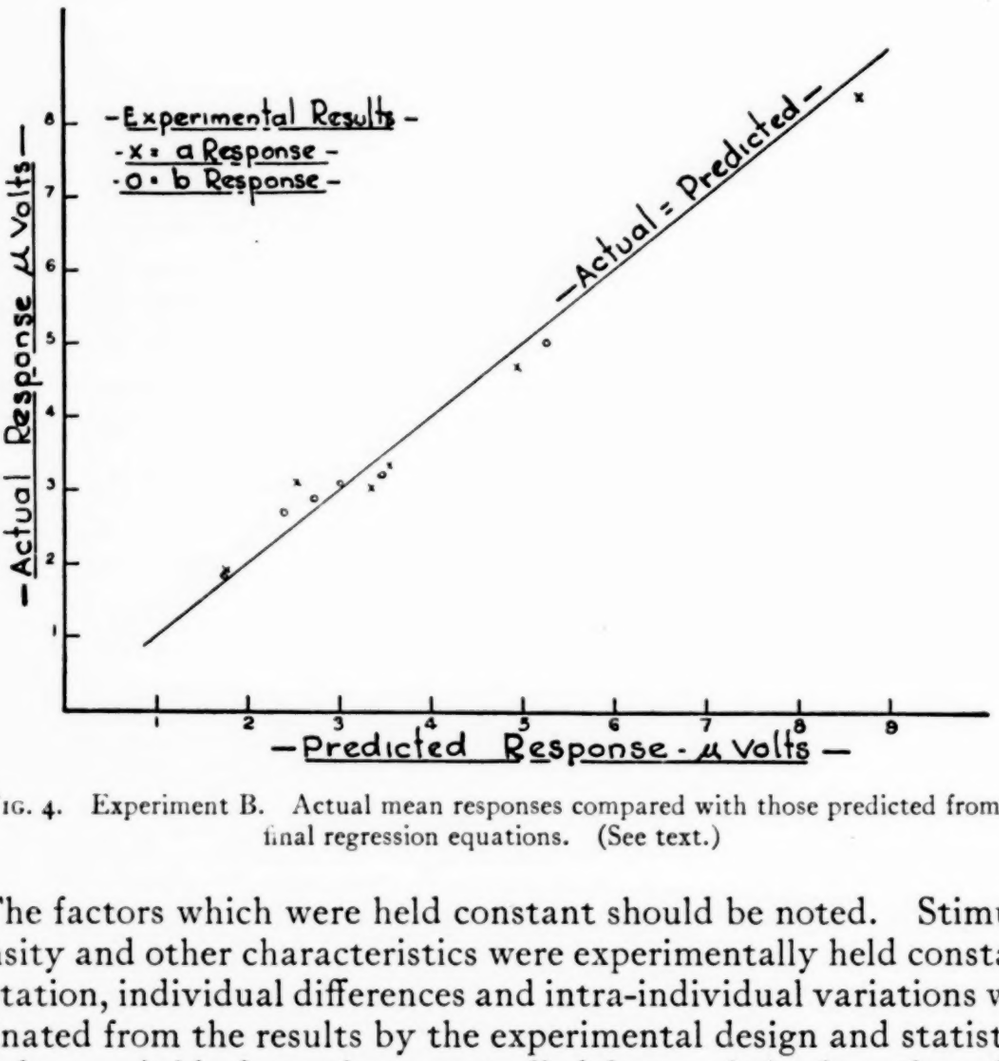

FIG. 4. Experiment B. Actual mean responses compared with those predicted from final regression equations. (See text.)

The factors which were held constant should be noted. Stimulus intensity and other characteristics were experimentally held constant; adaptation, individual differences and intra-individual variations were eliminated from the results by the experimental design and statistical procedure. Aside from these controlled factors it is clear that there are none of importance in this experiment which will influence the responses except such as operate by changing the level of pre-stimulus tension.

It seemed possible that this relationship to pre-stimulus tension might also account for the decline of the a-response with stimulus repetition. The amount of tension induced by the instructions does

fall off through the series of trials. But the decline is not nearly enough to account for the much greater falling off of the a-response. There must be an independent adaptation effect for the a-response.

Discussion

A general interpretation of the two responses of course must be postponed until more facts are available, but the application of the present results to the questions raised at the outset may be considered. Within the range of stimuli used there is a somatic response—really two responses—when the individual is under instructions to do nothing in response to the stimuli. This fact contributes to the understanding of metabolic, distractive and dynamogenic effects of sound stimuli. The role which these muscular reactions play in more specific responses to sound will be discoverable when their determining factors are known. Only the a-response has been shown to be affected by stimulus characteristics (intensity, repetition); what will happen with a wider range of stimulus variation remains to be seen. It may be that, under the conditions of the present experiments, b-responses lie on a rather flat portion of a complete curve of such functions. The antecedent condition of the organism, on the other hand, has been shown to play a major role in determining not only the size but also the nature (spatial distribution) of both responses. The stimulus enhances tension wherever tension previously exists, and enhances it more when the original tension is highly localized. An interpretation might be that a sound will reinforce any muscular activity already in progress, but reinforce it in differential fashion, so that it becomes more simplified.

So far as they went, the results the writer reported in the earlier publication are in agreement with those of the present study. A comparison of these with the description of the startle pattern given by Strauss (**12**) and Landis and Hunt (**10**) raises some interesting problems. Landis and Hunt's identification of the 'muscular tension reflex,' as the a-response was called in the earlier publication, with a part of the startle pattern seems reasonable because the a-response occurs at about the same time as the startle pattern reaches the arm. It is, however, a response on the 'implicit' level, and the two seem to have different properties. Adaptation of the a-response will reduce it practically to zero in all *S*s, while Strauss, Landis, and Hunt found the response in some *S*s quite resistant to stimulus repetition. Preliminary position and tension are very effective in influencing the a-response, while earlier investigations reported that it had no effect on the startle reaction. Strauss, however, found that a movement in progress would prevent the startle reaction in the part moving. Except for these and some cases Strauss calls 'atypical,' the response is described by these investigators as always symmetrical. Disregarding the possibility that photographs might not reveal quantitative trends, the difference in the

intensity of the stimulus in this and former studies may explain the difference in results. With a stronger stimulus possibly the response is not only increased, but also more stereotyped and less subject to modifying influences.

In the earlier studies there are also reports of a second response. Strauss found these occurring occasionally. They are described as unsymmetrical and classified into four types, depending on the direction of movement. Landis and Hunt suggest a classification of curiosity, fear, annoyance and overflow effects, plus two more stereotyped varieties which do not fit the classification. If one considers all responses which follow the stimulus, however remote, particularly in the social situation produced when an *E* is present, a great variety would be expected. In general discussion Landis and Hunt remark that it is in the 'gap' between "primitive individual response and social stereotype" that their secondary behaviors lie. The b-response of the present study is possibly one that would develop into these 'intermediate' responses with a stronger stimulus. With electrical recording methods it may be found more generally present than photography would show, and the postural effects here described may account for some of the variety found by both Strauss and Landis and Hunt.

Double responses to single stimuli have been found in several other instances. The 'fast type' and 'slow type' of conditioned knee jerk reported by Wendt (13) have latent periods about the same as that of the a- and b-responses. Whether conditioning is necessary to establish the b-response is, of course, unknown. The bimodal distribution of eyelid reaction latencies reported by Grant (7) would signify, as he points out, the existence of two varieties of response, which differ further in that the one of larger latency is subject to sensitization. Latent times for these eyelid responses seem somewhat shorter than those for the responses here studied, showing a difference which should probably be expected between an eyelid and an arm reaction. Possibly the occurrence of double responses to single stimuli is more usual than has been thought.

Summary

To study possible motor responses to sensory stimuli two experiments were conducted in which there was a recording of muscular action potentials in both forearms under loud sound stimulation, the *S*s being under instructions to do nothing in response to the stimuli. An increment in action potential over the immediate pre-stimulus level was considered to be a response. The first experiment was designed to study the nature of the response and the effects of stimulus intensity and repetition on it. The second was to investigate the effects of pre-stimulus tension pattern upon the response, and used states of induced tension in the left and right arms, in addition to a 'normal' condition. The following results were obtained:

1. Stimuli of the sort used here may be said to produce two responses, called a and b, since two parts of the over-all response curve have different functional relations.

2. The a-response has a latency of about 0.1 sec., reaches its peak during the next 0.1 sec. after the stimulus onset, and in large part disappears during the next 0.5 sec.

3. The a-response shows marked and rapid adaptation, practically disappearing with a half dozen stimulations two min. apart.

4. The a-response varies with stimulus intensity, and probably would not appear with a stimulus of much less than the 90–100 db. at 500 cycles here used.

5. The b-response, the latency of which cannot be determined exactly from these data, reaches its maximum generally about one sec. after the onset of the stimulus, and on the average stays at that level for about another sec., thereupon declining.

6. The b-response is not affected by stimulus intensity or repetition within the limits of the experiment.

7. Both a- and b-responses are closely related to the state of tension existing just before the delivery of the stimulus. The size of both reactions is a function of this tension level, and the geographical patterns are dependent upon it. The response pattern is not, however, in simple conformity to the pre-existing tension pattern: response excitation in one location is facilitated by ipsilateral tension and slightly inhibited by contralateral tension.

These responses are probably related to some previously studied by other methods, but a complete theory must await more information.

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References

1. Berrien, F. K. The effects of noise. *Psychol. Bull.*, 1946, **43**, 141–161.
2. Clites, M. S. Certain somatic activities in relation to successful and unsuccessful problem solving. *J. exp. Psychol.*, 1936, **19**, 172–192.
3. Daniel, R. S. The distribution of muscular action potentials during maze learning. *J. exp. Psychol.*, 1939, **24**, 621–629.
4. Davis, R. C. The muscular tension reflex and two of its modifying conditions. *Ind. Univ. Science Series*, 1935, No. 3, pp. 21.
5. Davis, R. C. Patterns of muscular activity during 'mental work' and their constancy. *J. exp. Psychol.*, 1939, **24**, 451–465.
6. Davis, R. C. The design and testing of multiple amplifiers for action potential recording. *J. exp. Psychol.*, 1943, **32**, 270–274.
7. Grant, D. A. A sensitized eyelid reaction related to the conditioned eyelid response. *J. exp. Psychol.*, 1945, **35**, 393–403.
8. Hovland, C. I., & Riesen, A. H. The magnitude of galvanic and vasomotor response as a function of stimulus intensity. *J. gen. Psychol.*, 1940, **23**, 103–121.
9. Jacobson, E. Electrophysiology of mental activities. *Amer. J. Psychol.*, 1932, **44**, 677–694.
10. Landis, C., & Hunt, W. A. *The startle pattern.* New York; Farrar & Rinehart, 1939, pp. xiv + 168.
11. Shaw, W. A. The distribution of muscular action potentials during imaging. *Psych. Rec.*, 1938, **2**, 195–216.
12. Strauss, H. Die Zusammenschrecken. *J. Psychol. Neurol.*, Lpz., 1929, **39**, 111–231.
13. Wendt, G. R. Analytical study of the conditioned knee-jerk. *Arch. Psychol.*, 1930, **19**, 1–97.

THE RELATIONSHIP BETWEEN UNIMANUAL AND BIMANUAL HANDEDNESS *

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Introduction

The question with which this investigation is chiefly concerned is that of the relationship between unimanual and bimanual handedness. Is there a right-handed and a left-handed way of performing a given bimanual activity, such as sweeping with a broom, for example, or using a shovel?

A review of the literature reveals that apparently this question has never been approached on a clearly empirical basis. Studies which have dealt with bimanual activities have seemed to involve the unexamined assumption that there is a right-handed and a left-handed way, universally agreed upon, to perform such activities, and investigators have proceeded, without testing this assumption, to determine 'bimanual handedness.' In testing bimanual handedness, for example, Ojemann (**9**) used four tests. These were sweeping, raking, shoveling and batting; and they were scored as indicating right- or left-handedness according to whether the *S* held the right or left hand nearer the 'business' end of the instrument and did the work on the right or left side of the body. Rife (**10**) and Downey (**1**) had earlier used this same procedure and found that the majority of their *Ss* swept left-handed. Rife's conclusions were based upon general observations without experimental or statistical refinements. Ojemann obtained results similar to these of Rife and Downey. He concludes that the customary classification as applied to sweeping, raking and shoveling cannot be very serviceable. Therefore, he reverses the customary classification of handedness as applied to these activities. The unexamined assumption that there are right-handed and left-handed ways to perform bimanual activities still remains, however.

Ojemann (**8**) in testing unimanual handedness used five tests. These were ball-throwing, needle-threading, tapping, paper-cutting and block-packing. When the combined scores on the five tests were presented graphically, the resulting curve was bimodal. Ojemann concluded that

* This article is a major portion of a thesis presented to the faculty of the Department of Psychology of the State University of Iowa in partial fulfillment of the requirements for the M.A. degree. The writer is indebted to Professor Wendell Johnson who directed the study, to Professor C. E. Buxton for suggestions concerning the unimanual handedness questionnaire used in the study, and to Professors C. R. Strother and J. B. Stroud for allowing the *E* to select *Ss* from their classes in elementary psychology.

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handedness is distributed bimodally, and relatively few individuals are ambidextrous. If a relationship exists between unimanual and bimanual handedness this dichotomy may carry over into bimanual activities.

Johnson and Duke (4) measured hand usage in fifty six-year-olds in terms of the dextrality quotient, the dextrality quotient being the percentage of the total achievement involved in any test of handedness which is to be credited to the right hand. In a later study by Johnson and Duke (5), revised dextrality quotients of six-year-olds were obtained. The authors found evidence indicating that handedness, in terms of hand usage as measured by them, is largely learned. Moreover, they found the distribution of the dextrality quotients to be skewed and essentially unimodal. This contradicts the findings of Ojemann and may be expected to have the reverse implications for bimanual handedness.

Problem

In the present study an attempt is made to determine the extent to which highly right- and left-handed individuals, as classified with reference to unimanual activities, can be differentiated with respect to the way in which they perform specified bimanual activities. A secondary consideration is that if there are bimanual performances which do serve to differentiate unimanually right- and left-handed persons, such performances should provide a means of defining operationally, and so of measuring, right and left bimanual handedness.

Subjects and Procedure

Unimanual hand usage questionnaires were administered to 386 students enrolled in the elementary psychology courses at the State University of Iowa in an effort to select from this sampling two groups of *Ss*, highly right-handed and highly left-handed individuals. The final selection consisted of 50 *S*, 25 of whom were considered highly right-handed and 25 of whom were considered highly left-handed with respect to unimanual activities. Of the 25 right-handed *Ss*, 12 were males and 13 were females. Of the left-handed group, 8 were males and 17 were females.

The hand usage questionnaire covered 25 unimanual activities, and is a modification of that devised by Koch (7). For her total series of tasks Koch obtained a reliability coefficient of .925, and responses to her questionnaire and actual performance tended to agree 76 to 94 percent of the time, showing a rather high degree of validity.

The questionnaire was scored by assigning weights ranging from -2 to $+2$ according to whether the *S* indicated that he performed a particular activity, for example, throwing a baseball, consistently with the left hand (-2), consistently with the right hand ($+2$) or with either hand (0). Scores of -1 and $+1$ were assigned to those activities which the *S* indicated that he performed most of the time, but not always, with the left or right hand. The sum of these weights was then divided by the number of items to give a handedness index. Thus, an index of -2.00 would indicate the maximum degree of left handedness that could possibly be attained on the questionnaire, and an index of $+2.00$ the maximum possible degree of right handedness that could be attained. The mean handedness index for the right-handed group was 1.83, and the mean index for the left-handed group was -1.53. The standard deviations for the two groups were .17 and .27, respectively.

Having selected the *Ss* on the basis of scores on the unimanual questionnaire the next consideration was to construct a battery of bimanual activities. The battery that was constructed consisted of 20 fairly common activities in which both hands participated. The manner of

shifted by an amount proportional to the increase in the level of the noise. The curve shown in Fig. 2 is typical of all the curves of that nature obtained in these experiments.

Since the primary purpose of the experiments was to determine the relation between the masked threshold and tonal duration, it was decided to average all the scores for the four highest noise levels. This procedure provided more reliable threshold measures. Table I gives the average threshold values for all the frequencies and dura-

TABLE I

THE RELATION BETWEEN TONAL DURATION AND THE SIGNAL-TO-NOISE RATIO NECESSARY FOR MINIMUM DETECTABILITY

Noise is measured in terms of energy per one-cycle band widths.

Duration (msec.)	400 cps	670 cps	1000 cps	1900 cps
12.5	33.9	33.8	31.9	33.1
25	30.7	30.2	29.8	30.8
50	26.9	26.9	26.0	28.7
100	24.1	24.3	23.4	25.8
200	20.2	21.3	20.3	22.7
500	18.5	18.8	18.0	21.3
1000	16.5	17.0	18.4	21.3
2000	16.5	17.1	17.5	20.7
inf.	14.9	15.7	16.8	20.2

tions used. It will be noticed that a value for infinite time is presented in the table. This value is not empirically determined, but has been computed, and the meaning of the computed value will become clearer in the discussion. These same values have been plotted in Fig. 3, with a different symbol for each frequency. Although the points for each of the four frequencies do not fall on the same line, they all present so nearly the same general shape that it seemed permissible to draw one curve through all the points. The curve as drawn has no theoretical significance, but is merely the best visual fit.

The most significant fact about these data is the linear relation between the logarithm of duration and threshold intensity (expressed in decibels) for tonal durations of less than 200 msec. Furthermore, the slope of this line indicates that there is linear integration of acoustic energy up to durations of 200 msec. Thus when the duration is increased by a factor of 10, the S/N ratio is decreased by 10 db, which is also a factor of 10 in terms of acoustic energy or in terms of instantaneous electrical power. The equation for the linear portion of the curve below 200 millisec. is

$$S/N + 10 \log_{10} t = 44.2,$$

where S/N is the signal-to-noise ratio expressed in decibels, and t is duration of the tone in msec.

Above 200 msec., the curve gradually flattens out until there is relatively little change in the S/N ratio when the duration of the tone is increased by fairly large amounts. The integration can be considered effectively complete after about one sec. Any further increase in duration has practically no effect on the stimulus intensity required for minimal audibility.

Discussion

The practical problem is simply the determination of how much loss in sensitivity one ought to expect if the duration of a signal is

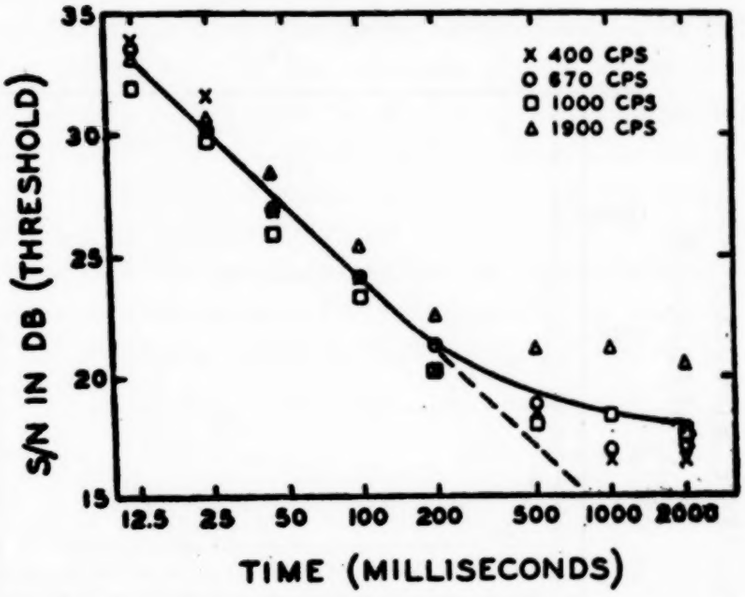

Fig. 3. The relation between the masked threshold of a pure tone and its duration. Noise energy for the S/N is in terms of energy per one-cycle band widths. Each plotted point is the average of measurements for the four highest noise levels, i.e., is the average of 160 observations. The heavy line is a visual fit of the data, and the dashed line is the extension of the curve which represents linear integration.

decreased. The theoretical problem is more than that. What we should like to know is the manner in which the ear integrates acoustic energy. Is it a simple linear integration, occurring only within limited ranges, or is the relation more complicated?

Thus far the data have been presented on log-log plots. An examination of the linear relation between the two variables sheds some light on the general problem. Fig. 4 shows this relation for the 1900 cps tone. Time in this case has been plotted on a linear scale, and the decibel readings for the S/N ratios have been converted into equivalent linear units, the conversion being on the basis of energy, and not pressure. As the time gets shorter and shorter, the stimulus intensity required for the tone to be heard becomes much greater,

and the curve seems to be approaching zero time as its asymptote, with infinite intensity. On the other hand, the threshold becomes lower and lower as the time is increased, but the curve does not seem to be approaching zero intensity as its asymptote. Rather it seems to approach some finite value of stimulus intensity. Altogether, however, the general shape of the curve is certainly that of the usual reciprocal relationship.

From the shape of this curve, it seems quite possible that there is some sort of linear integration, although the integration does not start with any arbitrary zero intensity, but with some value which is effectively zero for the ear. If this is correct, we should no longer expect that the relation between time and intensity would be $It = C$, which is a statement of perfect linear integration.

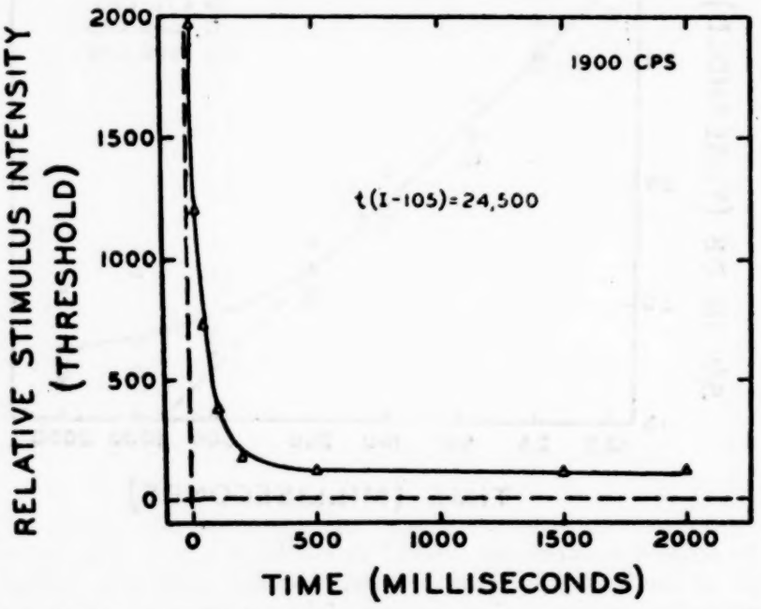

FIG. 4. The relation between the masked threshold of a pure tone and its duration. Both stimulus intensity and time are plotted on linear scales.

Hypothesis: There is certain minimal stimulus intensity (I_0) *which is not an effective stimulus for the ear. The ear will, however, integrate all stimulus energy above this minimal value, and this integration is linear with time.* Expressed in mathematical form, the following relation should be true.

$$t\,(I + I_0) = C.$$

In this equation, t is linear, and both I and I_0 are expressed in terms of energy.

It should be noted that this equation is of the same mathematical form as that used by Hecht (5) to express the same relation for vision, although the general equation is derived on the basis of an entirely different logic. Hecht states the equation in the form $It = C + Dt$,

in which the constant D is small compared to the constant C. This constant D is a result of an adaptation process going on with time, and the quantity Dt will have very little effect when t is small, but will have progressively more effect as t gets larger and larger. Wald (**8**) has also stated a similar equation, on still other grounds, to express the relation between visual area and threshold.

In order to test this hypothesis graphically, several mathematical transformations of the data were required. First, for each S/N ratio, for each of the four frequencies, the equivalent linear quantity (in terms of energy) was computed. With these linear values, the asymptotic value for each of the four frequencies was then computed by the method of least squares. The quantity $I - I_0$ was then determined by subtracting the computed asymptotic value from each linear value of stimulus. If the relation $t\,(I - I_0) = C$ is a true relation, then a log-log plot of the value $I - I_0$ and t should be a straight line, since $\log t + \log (I - I_0) = \log C$. Each value of $I - I_0$ was therefore reconverted into an equivalent decibel scale, and plotted as a function of the logarithm of time. This plot is shown in Fig. 5. Each of the four curves has had its time scale shifted to some extent, so that the intercept constant of the four curves is the same, and they can all be fitted with the same straight line.

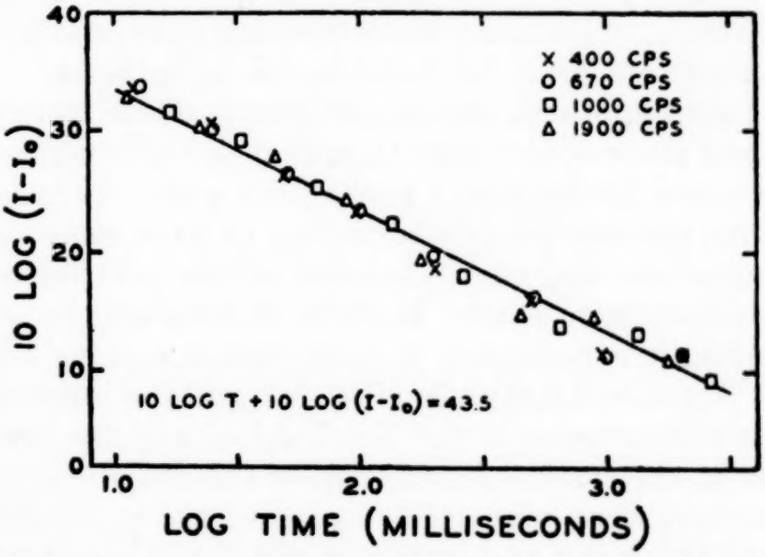

FIG. 5. The relation between the duration of a tone and the masked threshold in terms of $I - I_0$.

This graph is a test of the hypothesis that the ear integrates acoustic energy linearly above a stimulus value which is effectively zero for the ear. The plotted points in this curve are derived from the data of Fig. 3, and each of the four curves for frequency has had its time base shifted to equate the intercept constants.

The straight line drawn in Fig. 5 is the theoretical line which all the points should fit if the hypothesis is perfectly substantiated. Although the fit is far from perfect, it is nevertheless clear that, ac-

cording to this hypothesis, acoustic integration by the ear continues well beyond 200 msec. It should be remembered that in assuming linear integration, there is only one degree of freedom allowed in fitting the data to the curve. The intercept constant is that degree of freedom. If a second degree of freedom had been allowed, in the form of a slope constant, then the fit would have been even more adequate.

Another interesting fact about this particular hypothesis is that the intercept constants for the four curves are quite similar. These constants are (expressed in terms of the logarithmic statement of the equation) 43.6, 43.5, 42.3, and 43.9 for the frequencies 400, 670, 1000 and 1900 cps respectively. In the plotted form, all the data have been corrected so that each curve has the same intercept constant.

Crozier's statistical theory

Crozier's theory (**2**) states in essence that the relation between stimulus threshold intensity and stimulus duration is such that if the reciprocal of I is plotted as a function of the logarithm of t, the resultant curve should be the normal probability integral. This relation is expected on the assumptions that the thresholds of neurons are normally distributed, and that this distribution is reflected when sensitivity ($1/I$) is plotted as a function of duration. Crozier's theory has seemed adequate for many kinds of visual data, and it seemed possible that these data could be fitted by his hypothesis.

To test that hypothesis the reciprocals of all the data points were computed, and these scores were then changed into percentage scores so that they could be fitted on a probability grid. In order to change the scores into percentages it is necessary to have some value for 100 percent integration, and the reciprocals of the previously computed asymptotic values were used. In order to have all the scores fall on the same curve, it is necessary to have identical slope and intercept constants. With a normal probability integral the intercept constant is equivalent to the mean of the distribution, and the slope constant is equivalent to the standard deviation of the distribution. All time values, therefore, were converted into what are essentailly standard scores so that the mean and intercept constants would be the same.

These corrected data are plotted in Fig. 6, and the straight line drawn there is the theoretical curve which all the data should fit if the hypothesis is substantiated. It can be noticed that this fit is about equally as good as that of the previously tested hypothesis. The main difficulty with this test is that only one or two points go beyond +1 standard deviation in the distribution, and the last six points all fall on the same side of the theoretical curve. Since very little curvature occurs in the normal curve up to one standard de-

viation, these data should not be considered an adequate test of the hypothesis.

It should be pointed out that this test allowed one more degree of freedom in its fit than did the previous hypothesis. Neither the slope of the curve nor the intercept constant were fixed by the hypothesis, so that the data were in effect both rotated and shifted in order to fit the hypothesis. The previous hypothesis, it will be recalled, allowed only one degree of freedom in its fit.

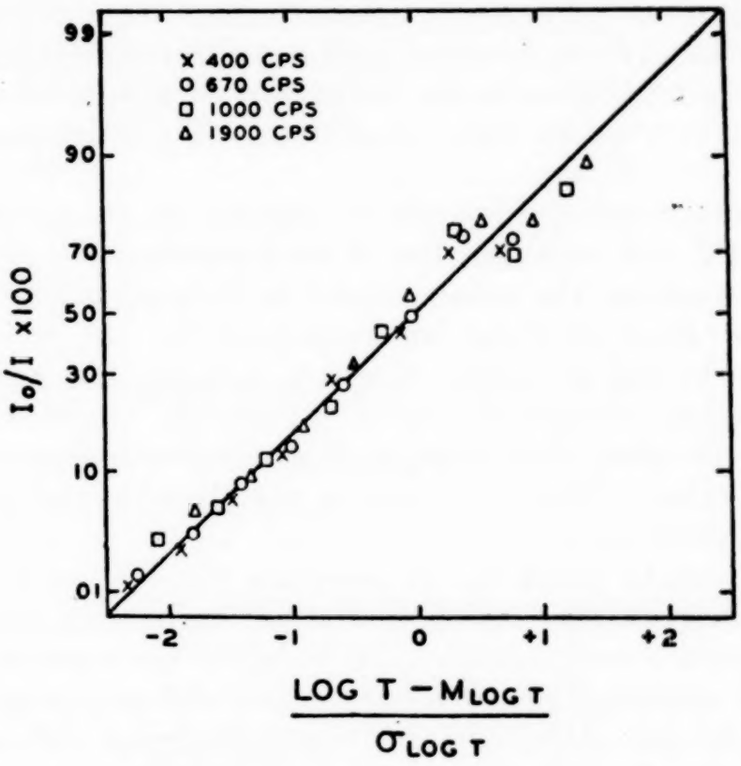

FIG. 6. The relation between the duration of a tone and the masked threshold in terms of probability theory.

This graph is a test of Crozier's statistical theory. The plotted points in this curve are derived from the data of Fig. 3. The reciprocal of *I* in terms of percentage has been plotted on a probability grid, and the values of time have been changed so that each of the four curves has the same slope and intercept constants.

In graphically testing the hypothesis of a sigmoid fit, it is necessary, of course, to convert sensitivity scores into equivalent percentage scores, and this requires, as mentioned previously, a value for 100 percent. For that value, we chose the reciprocal of the previously computed asymptotes for each of the curves. It might be felt that in using that value, we were not doing full justice to Crozier's hypothesis. We have tried other values for 100 percent sensitivity, however, and the reciprocal of the computed asymptote provides the best fit of these data to Crozier's hypothesis.

Comparison of the two hypotheses

From the data available with these experiments, the two hypotheses seem about equally well substantiated. There are, however, certain mathematical relations between these two curves which should be discussed.

If we have a relation such that $It = C$, and if we plot the reciprocal of I as a function of linear t, then we will have a straight line relation, with the reciprocal of I becoming larger with increases in t. The slope of this line will depend on the constant C. If, however, we plot the reciprocal of I as a function of the logarithm of t, then we will have a monotonic rising function with a positive acceleration, and this curve will resemble greatly the lower part of a sigmoid curve. The top of the curve, under these conditions will continue to rise to infinity.

On the other hand, if we add a constant to I, and then plot the reciprocal of $I + C$ as a function of the logarithm of t, then as I gets smaller and smaller, the value of $1/(I + C)$ approaches the value of $1/C$, and we have provided an asymptote for the reciprocal of I. Then the curve will no longer extend to infinity, but will bend over, approaching the asymptotic value. Thus the curve starts with a positive acceleration, then changes to a negative acceleration with an asymptotic value. This, of course, is exactly what the normal probability integral does.

Thus, any data which fit the equation $t(I - I_0) = C$ will also fit fairly well the requirements of the normal probability integral, since when we plot $1/I$ rather than $1/(I - I_0)$ we have essentially added the constant necessary to provide the curve with an asymptotic value. Data which fit one or the other of these hypotheses will, of necessity, also fit the other hypothesis with some degree of adequacy. On this basis alone, then, it is difficult to choose between the two.

However, the assumption of linear integration for all intensities above an absolute minimum intensity is more stringent in its requirements, and seems simpler in principle than the assumption of an integration with respect to logarithmic time. Until more direct evidence is available, the elaborate and ingenious formulation proposed by Crozier should probably be regarded with a certain cautious conservatism.

Summary

In these experiments, the relation between auditory sensitivity and the duration of a pure tone was measured. Four different frequencies (400, 670, 1000 and 1900 cps), and eight different tonal durations (12.5, 25, 50, 100, 200, 500, 1000, and 2000 msec.) were used. Because of the difficulties involved in measuring the threshold of

hearing in the quiet with any degree of precision and reliability, the masked threshold was determined with a white-noise masking spectrum. The following results and conclusions are presented:

1. The ear integrates acoustic energy linearly up to 200 msec., for when the duration is decreased by a factor of 10, sensitivity is decreased by 10 db.

2. For durations longer than 200 msec., the change in sensitivity is slight, and acoustic integration may be considered complete at approximately one sec.

3. The hypothesis is presented that the auditory system integrates acoustic energy linearly, if the zero intensity is regarded as that inintensity which is effectively zero for the ear. The data substantiate this hypothesis fairly well.

4. Crozier's statistical hypothesis is also tested, and the data fit that hypothesis as adequately as they fit the previous hypothsis.

5. Mathematical relationships between the two hypotheses are shown such that if the data fit one hypothesis, they must of necessity fit the other.

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Bibliography

1. Békésy, G. v. Zur Theorie des Hörens. Über die eben merkbare Amplituden- und Frequenzänderung eines Tones. Die Theorie der Schwebungen. *Physik. Z.*, 1929, **30**, 721–745.
2. Crozier, W. J. The theory of the visual threshold. I. Time and intensity. *Proc. nat. Acad. Sci.*, 1940, **26**, 54–60.
3. Garner, W. R., & Miller, G. A. Differential sensitivity to intensity as a function of the duration of the comparison tone. *J. exp. Psychol.*, 1944, **34**. 450–463.
4. Garner, W. R., & Miller, G. A. The effect of duration on the masked threshold of tones. Part II in: *The masking of signals by noise*, Psycho-Acoustic Laboratory, Harvard University, Oct. 1, 1945, OSRD Report No. 5387. (Available through the Publications Board, U. S. Department of Commerce, Washington, D. C.)
5. Hecht, S. Vision: II. The nature of the photoreceptor process. In: Murchison, C. (Ed.), *Handbook of general experimental psychology*. Worcester, Mass.: Clark Univ. Press, 1934.
6. Lifshitz, S. Apparent duration of sound perception and musical optimum reverberation. *J. acoust. Soc. Amer.*, 1936, **7**, 213–221.
7. Turnbull, W. W. Pitch discrimination as a function of tonal duration. *J. exp. Psychol.*, 1944, **34**, 302–316.
8. Wald, G. Area and visual threshold. *J. gen. Physiol.*, 1938, **21**, 269–287.

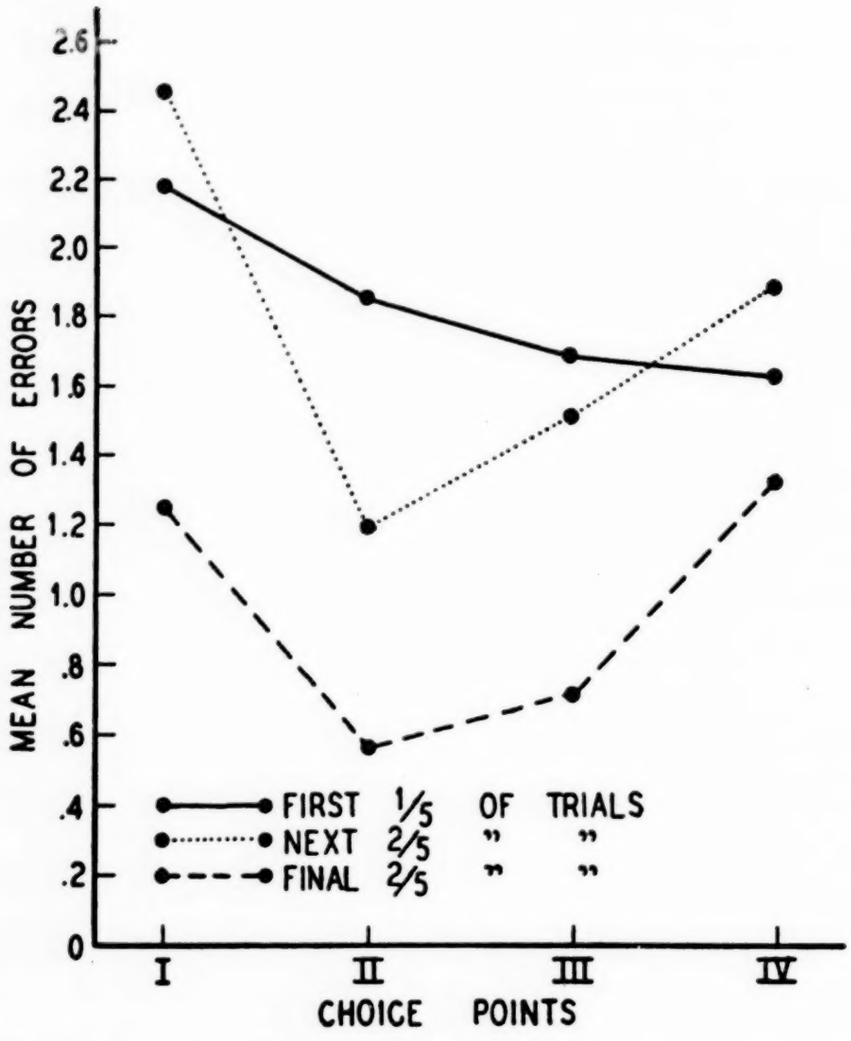

FIG. 2. Graphic representation of the mean number of first-choice errors at the four choice points during the first one-fifth, the next two-fifths, and the final two-fifths of learning trials. The means are based on errors made by 50 animals.

Fig. 2 and 3 show the development of the error gradient as learning progresses. At the beginning of training (during the first one-fifth of the trials) the error curve slopes consistently downward from the

TABLE II

DATA ON THE MEAN NUMBER OF FIRST-CHOICE ERRORS MADE AT EACH CHOICE POINT BY 50 ANIMALS DURING THE LAST ONE-FIFTH OF THE TRAINING TRIALS

Choice Point	Mean	σ	σ_M	Pairs of Choice Points	r	Diff.	$\sigma_{diff.}$	C.R.	P
I	.528	.651	.093	I, II	−.30	.284	.128	2.22	.99
II	.244	.453	.065	I, III	−.25	.172	.149	1.15	.87
III	.356	.667	.095	I, IV	−.15	.248	.164	1.51	.93
IV	.776	.851	.122	II, III	−.03	.112	.117	.96	.83
				II, IV	.03	.532	.136	3.91	1.00−
				III, IV	.29	.420	.131	3.21	1.00−

first choice point to the last. During the following two-fifths of the training trials there is a marked drop in the number of errors made at the second choice point and a smaller drop in the number made at the third choice point.[4] This produces an upward tilt in the graph from the second choice point to the fourth. Thus far our results are largely in agreement with those of Sprow (7, p. 202, Fig. 3). However, in the final two-fifths of training slightly more errors are made at the fourth choice point than at the first, a reversal of the previous tendency.

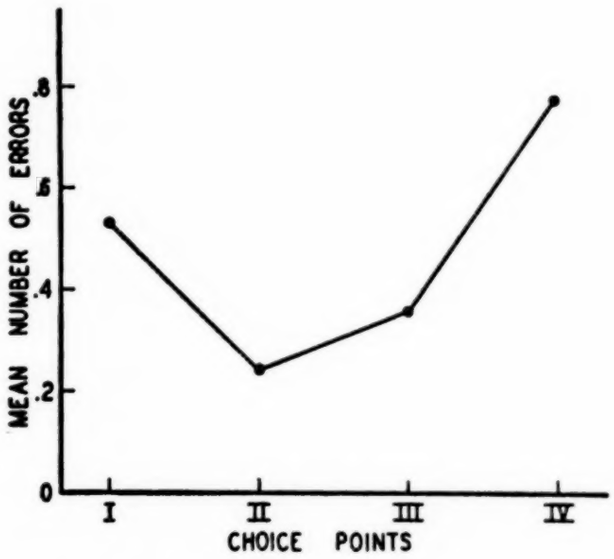

FIG. 3. Graphic representation of the mean number of first-choice errors at the four choice points during the final one-fifth of learning trials. The means are based on errors made by 50 animals.

During the last one-fifth of training (Fig. 3) the difference in number of errors made at the first and fourth choice points becomes even more marked than during the last two-fifths. Furthermore, the second choice point continues to have the fewest errors in the last stages of training. These results differ from Sprow's. The difference may be summarized by the observation that the general tendency of Sprow's data for the last stages of learning is to show more errors at choice point I than at choice point IV, while the general tendency of our corresponding data is the reverse of this.

DISCUSSION

At the very beginning of training, when the *S* has to learn a new path through the maze (since he was never trained to go through a

[4] The reader should note that the increased number of errors made at the first and fourth choice points does not represent poorer performance. The first *one*-fifth of trials is being compared with the next *two*-fifths, and therefore an equal number of total errors does not represent an equal number of errors per trial.

door for which he had shown preference on the habituation trials), each correct response at a choice point contributes greatly to the probability of a correct response at the next choice point on the same trial. Thus, the eventual successful choice at the first choice point makes success at the second choice point more likely, success at the second choice point makes success at the third more likely, and so forth. For this reason the error gradient during the earliest stage of training would be expected to fall continuously from the first choice point toward the fourth choice point. This expectation is fully confirmed, as may be seen in the error gradient for the first one-fifth of training trials (Fig. 2).

As training progresses the transfer effect from one choice point to the next becomes less and less marked and other factors become more important. The two principal factors are the type of reinforcement and the effect of stimulus generalization.

1. *The effect of serial reinforcement.*—It will be recalled that in serial reinforcement, reward is given after each choice point. It is assumed that each of these rewards produces a gradient of reinforcement (**3**, pp. 135–164) extending backward from the point of reward toward the beginning of the maze. Thus, there are four reinforcement gradients of various strengths at the first choice point, three at the second choice point, and so forth. These gradients summate to produce a gradient of reaction potential which is highest at the first choice point and decreases toward the fourth choice point (**5**, p. 24). In order to distinguish this gradient from the goal gradient we shall call it the *primacy* gradient. Since the number of errors is inversely related to reaction potential, the error gradient characteristic of serial learning should, other things equal, be lower at the first choice point than at the last.

2. *The effect of stimulus generalization.*—Because the choice points of the maze are as nearly identical as possible, almost perfect stimulus generalization should occur, i.e., a reaction learned at one choice point should be evoked at any other (**3**, pp. 183–203). However, the situation is complicated by the presence of perseverative stimulus traces (**3**, p. 385), which do not remain the same from one choice point to the next. Now, studies involving heterogeneous responses permit the independent recording of the various generalization gradients involved in such a situation (**4**, **5**) because the responses are all different and so distinguishable. These studies show that a double generalization gradient arises at each point of reinforcement, decreasing in both directions but more rapidly toward the posterior end of the maze (**4**, p. 128). Since a homogeneous reaction chain consists of a series of similar or identical acts, a response which is correct at one choice point is also correct at all others. Therefore, generalization facilitates

homogeneous learning. Since overlapping generalization gradients summate, the four generalization gradients produce a composite generalization gradient which is highest between the second and third choice points and decreases toward both ends. The effect of this composite generalization gradient is to make errors less likely in the center sections of the maze than at the two ends.

The combined effect of reinforcement and generalization in this situation is to produce an error distribution which is lowest at the second choice point and rises toward both ends, with its highest value at the fourth choice point. This error gradient produced jointly by serial reinforcement and generalization arises slowly in the course of learning and does not overcome the initial gradient (first one-fifth of the trials) and become fully established until the last stage of training. It can be seen most clearly during the last one-fifth of the trials (Fig. 3). The primacy component of the error gradient is seen in the greater number of errors made at choice point IV than at choice point I, and the greater number made at choice point III than at choice point II.

The reliability of these comparisons is shown by the probability values in Table II. While the probabilities (that the results are not due to chance) are not great enough to be highly significant, similar comparisons in four other studies of serial learning all confirm these results. In the portion of Arnold's study in which he used serial reinforcement of a four-response series where errors in the ordinary sense were not possible (**1**, pp. 60–74), it was found during the later stages of learning that the mean reaction latency was greater at the fourth manipulandum than at the first, and greater at the third manipulandum than at the second. Hull's study of serial learning (**5**) also showed the same trends. In a three-choice linear maze unpublished study reported by Hull (**6**) the first choice point showed fewer errors than the last. This was also reported in an unpublished study by Virginia Voeks.

The influence of generalization is seen in the greater number of errors made at choice point I than at choice point II and the greater number made at choice point IV than at choice point III. As shown by the probability values of Table II, both these comparisons are highly significant. These results are further confirmed by those of Sprow (**7**) and of Arnold (**1**, pp. 5–33).[5] In the latter two studies, as in the present one, generalization produces facilitation because the reactions are homogeneous.

[5] See also Arnold, W. J. Simple reaction chains and their integrations. I. Homogeneous chaining with terminal reinforcement. *J. comp. physiol. Psychol.*, 1947, **40**, 349–363. See especially p. 356.

The results of the present study and of the previous studies to which we have referred confirm the theoretical principles of serial and terminal reinforcement, together with the principles of generalization as stated by Hull. The general experimental results may be stated as follows:

1. *Reinforcement.*—Terminal reinforcement produces the greatest increase in reaction potential at the posterior end of the reaction chain, i.e., at the point of reward. This is the gradient of reinforcement (**3**, pp. 135 ff.), which rises from the beginning to the end of the reaction chain whether associated with heterogeneous or with homogeneous responses (**2**, **4**, **7**). Serial reinforcement produces the greatest increase in reaction potential at the beginning of the reaction chain, i.e., at the point of first reward, also whether associated with heterogeneous or with homogeneous responses as shown by Hull (**5**) and by the present study.

2. *Generalization.*—In heterogeneous reaction chains generalization interferes with effective learning. The interference gradient of error is low at each end and highest in the center (where interference is greatest), whether associated with serial or with terminal reinforcement (**5**, **2**, **4**). In homogeneous reaction chains generalization facilitates learning. The resulting gradient of error is high at each end and lowest in the center (where facilitation is greatest), also whether associated with serial or with terminal reinforcement, as shown by Sprow (**7**) and the present study.

Summary

Albino rats were trained to go through the same door at each choice point of a four-choice-point linear maze with food reward after each choice point. Data from 50 animals are analyzed to show the development of the error gradient in the course of learning. The gradient develops as follows:

1. In the earliest stage of training the error gradient falls consistently from the first choice point to the fourth.
2. As training progresses, relatively fewer errors are made at the second and third choice points, so that the gradient rises from the second choice point to the fourth choice point, but continues to fall from the first choice point to the second.
3. In the later stages of learning the errors made at the first choice point are eliminated more rapidly than those at the fourth choice point, with the result that the final form of the error gradient is markedly higher at the fourth choice point than at the first.

An interpretation of these phenomena is offered on the basis of the primacy reinforcement gradient and stimulus generalization.

(Manuscript received July 7, 1947)

References

1. Arnold, W. J. Simple reaction chains and their integration. Ph.D. thesis, 1946, on file in the Yale University Library.
2. Hill, C. J. Goal gradient, anticipation, and perseveration in compound trial-and-error learning. *J. exp. Psychol.*, 1939, **25**, 566–585.
3. Hull, C. L. *Principles of behavior.* New York: D. Appleton-Century Co., Inc., 1943.
4. Hull, C. L. Reactively heterogeneous compound trial-and-error learning with distributed trials and terminal reinforcement. *J. exp. Psychol.*, 1947, **37**, 118–135.
5. Hull, C. L. Reactively heterogeneous compound trial-and-error learning with distributed trials and serial reinforcement. *J. exp. Psychol.*, 1948, **38**, 17–28.
6. Hull, C. L. Compound trial-and-error learning—pure forms. (Unpublished manuscript)
7. Sprow, A. J. Reactively homogeneous compound trial-and-error learning with distributed trials and terminal reinforcement. *J. exp. Psychol.*, 1947, **37**, 197–213.

THE ILLUSORY PERCEPTION OF MOVEMENT CAUSED BY ANGULAR ACCELERATION AND BY CENTRIFUGAL FORCE DURING FLIGHT. II. VISUALLY PERCEIVED MOTION AND DISPLACEMENT OF A FIXED TARGET DURING TURNS [1]

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Adequate orientation during flight is a problem of the first importance for all pilots of aircraft and various methods have been designed to aid the pilot in making judgments of his position in space. In spite of these aids, disorientation is not uncommon, particularly during instrument and night flights (**2, 6, 10, 11**). A systematic investigation of this problem of disorientation or 'vertigo,' as it is usually termed by pilots, has been conducted at the Naval School of Aviation Medicine. This investigation has included laboratory studies (**2, 3, 4, 5, 9**), reports of pilots' experiences (**11**) and studies of illusory experiences during flight (**2, 6**). It is with the third type of experiment that this report is concerned.

Test trials using the method described in Part I (**6**) of this study demonstrated that visual perception in flight is influenced to a considerable degree by angular accelerations, and by the forces of radial and linear accelerations usually referred to as 'g' (one 'g' equals the force of acceleration due to gravity.) It was shown that angular acceleration and centrifugal force in amounts produced in normal flight induce marked illusory perceptions of both motion and displacement of an objectively motionless target in the dark. It is the purpose of this experiment to define the thresholds, occurrence, and the magnitude of these illusory effects while executing coordinated turns during flight.

[1] The experimental work was carried on under the auspices of the Bureau of Medicine and Surgery, Navy Department, at the School of Aviation Medicine and Research, Naval Air Station, Pensacola, Florida. The opinions or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views or the endorsement of the Navy Department.

Apparatus and Procedure

The apparatus and method used here to study the effects of centrifugal force and angular acceleration on the binocular perception of an object have been described in detail in Part I (**6**). The *S* sat in the rear cockpit of an SNJ-6 aircraft and observed a fixed collimated 'star' which consisted of a spot of light with six radiating lines. The star was observed in complete darkness while the *S* faced straight ahead. The three *S*s who made observations were the authors. All three had had considerable experience in reporting these effects both in the laboratory and in flight (**2, 3, 4, 5, 6, 9**).

Each *S* gave a running verbal account of the apparent movement of the star. This report was automatically inscribed on a wire recorder which ran continuously during any given trial and hence provided a time line for the reports. The observer reported three things: (a) motion, (b) displacement, and (c) rotation of the test object. As in the earlier reports *motion* referred to the perception which defines a body as not being at rest; *displacement*, on the other hand, referred to a change in location; while *rotation* indicated a turning about a center point in the plane of the star's radiating lines. These three effects could occur together or separately. Direction of motion was indicated by reference to the numbers on the face of a clock. The *S* also estimated the amount of rotation and displacement using five-degree intervals from an egocentrically localized 'true' position of the star. Although these estimates were entirely subjective, each *S* was sufficiently consistent with himself to permit the judgments to be meaningful. The presence or absence of these three types of motion were reported at regular intervals throughout each trial.

The pilot indicated critical points in each maneuver by means of a time signal on the wire. As the pilot began to drop the wing for each turn he said ABLE into the microphone. BAKER indicated that the plane was in the desired attitude for the turn; CHARLIE was said one min. after ABLE and indicated that the pilot was beginning to recover from the turn; and DOG indicated that recovery was complete, and straight and level flight had been resumed. The trials began from straight and level flight which had been maintained for at least 30 sec., and each trial terminated after one min. of straight and level flight. The order of the trials was random, prearranged in advance by the pilot, and hence unknown to the observer. The following six banks were used: 10°, 18°, 30°, 40°, 50°, 60°.

The degree of bank was maintained without gaining or losing altitude. This was accomplished in two ways. In the first series of experimental runs, the pilot set the airspeed at 130 mph for straight and level flight. As he banked he pulled back on the stick raising the nose of the plane. This increased the angle of attack[2] of the wing, providing greater lift and making it possible to maintain the same altitude at the expense of a loss in airspeed. This loss in airspeed was negligible for the shallower banks, reaching a maximum of approximately 25 mph at the 60° bank. These maneuvers produced a change both in magnitude and direction of the resultant force on the body. The magnitude of 'g' increased with the secant of the angle of bank. As the angle of attack increased, the direction of the resultant 'g' force on the *S* changed to a theoretically calculated maximum of approximately 12°. In effect it was as if the *S* were tilted backward in the seat while the direction of the force remained constant. This series of observations will be referred to hereafter as the Variable Angle of Attack Series. Twelve trials were flown for each *S* at each degree of bank.

In a second series of trials the pilot maneuvered the aircraft at the same six banks as in the first series, but instead of using a constant power setting and increasing the angle of attack to maintain altitude, he began each trial at an airspeed of 100 mph and increased the speed to maintain the necessary lift as he assumed the proper turning attitude. This increase in speed was negligible in 10° banks and reached a maximum of 41 mph at the 60° bank. There were 18 experimental flights (six for each *S*) with 18 turns to the right and 18 turns to the left for each degree of bank studied. This will be referred to as the Constant Angle of Attack Series.

A third series of tests was also run using the first method of turning, as a control for the effect of practice. In this series, tests were flown only at 18°, 40°, and 60°. There were 18 turns to the right and 18 to the left for each of the three angles of bank.

This experimental plan made it possible to compare the illusory effects using two methods of assuming a turn. It also gave data concerning the effect of habituation to the experimental

[2] The angle between the mean wing chord and the relative wind or essentially the angle between the wing chord and the flight path.

situation. All data from the wire recordings obtained in flight were transcribed into a written protocol in the laboratory. All time relations were made from an arbitrary zero taken at the pilot's signal that the trial had begun. As in the previous study (**6**), the time for each report by the subject was recorded in the protocol to the nearest second, and each record was checked at least once. The analysis of the data was then made from these protocols.

Results

The data for the three experimental series are summarized in Tables I–III. Since the nystagmus resulting from angular acceleration will cause an apparent motion of the star in the direction of turn (**3, 4, 6, 9**), the data for turns to the right and left have been combined. Hence, the analysis of the apparent motion has been in terms of its correspondence to the direction of turn.

TABLE I

Average Time Intervals for Various Segments of the Maneuvers

A–B = time required to attain the turning attitude; B–C = time interval the bank was maintained; C–D = time required to resume straight and level flight; A–E = total time for the trial. The intervals are indicated in seconds, the acceleration and deceleration in degrees/sec.^{2} The g force is the theoretical value for each bank. The lines marked V are for the variable angle of attack; the lines marked C are for the constant angle of attack.

Angle of Bank		10°	18°	30°	40°	50°	60°
A–B	C	11.4	14.2	16.2	18.1	20.9	27.8
	V	12.5	13.2	15.8	17.9	21.6	24.2
B–C	C	47.9	45.5	43.4	42.0	37.7	31.0
	V	40.0	46.1	44.7	42.6	38.3	34.8
C–D	C	11.2	11.9	12.4	14.1	15.6	17.9
	V	11.0	10.9	13.0	12.8	12.8	12.7
A–E	C	128.2	129.2	128.1	136.0	135.2	140.4
	V	129.7	128.7	132.3	132.5	131.5	131.6
Av. acc. A–B	C	0.17	0.25	0.34	0.40	0.53	0.51
	V	0.13	0.21	0.30	0.39	0.50	0.60
Av. dec. C–D	C	0.18	0.29	0.44	0.51	0.71	0.79
	V	0.14	0.26	0.36	0.54	0.85	1.13
g	C & V	1.02	1.05	1.15	1.31	1.56	2.00

The data describing the behavior of the plane are given in Table I. The table shows that in banks up to and including 50° the time to assume the angle of bank (A–B) and the time to recover (C–D) vary little between the methods using the constant and variable angles of attack. At 60° the pilot took substantially more time both to attain the bank and to recover during the constant angle of attack procedure.

The calculated average angular accelerations during the turns were determined by dividing the average measured velocity of turn

at each bank by the time to attain that velocity or to recover straight and level flight. This estimate fails to reveal the fact that acceleration within this period was not constant, and occasionally reached very high values. It was used because an accelerometer was not available to measure the accelerative forces. For all degrees of bank the variation in the average angular acceleration between the two methods lies in the second decimal place. This is also true of the deceleration from 10° to 40°. In the 50° and 60° banks the deceleration was much slower in the maneuver which maintained a constant angle of attack. The data which describe the behavior of the aircraft during the retests did not differ significantly from those obtained during the original tests. The maximum 'g' forces, being a function of the angle of bank, were the same in both situations. It should be emphasized that these data represent the means of 36 trials at each degree of bank and that small variations in the behavior of the aircraft within the trials caused some change in the stimulus situation.

The actual banking movement of the aircraft also introduces a rotation about the longitudinal axis of the plane. Its duration is coextensive with the time required to set the plane up in the desired bank (A–B). The velocity of this rotation is measurable, but the angular accelerations cannot be known in this situation, since only the beginning and end points are identified.

1. *Illusory effects observed while assuming the turn and during the turn proper.*—The percent occurrence of the illusions of motion and displacement upward in the three experimental series are shown in Table II. The direct relation between the angle of bank and the frequency of observed motion and displacement is apparent throughout. There were no significant differences among the frequencies in the three situations at any level for either motion or displacement, except that during the 18° banks there was a substantial reduction in the occurrence of apparent displacement during the retest. This was significant at the one percent level of confidence, and all three Ss exhibited this reduction. However, the hypothesis that habituation occurs is not unequivocally established, since this is the only point where a significant difference appears. It is clearly established, nevertheless, that there is no significant difference in the percent occurrence of motion and displacement between the two methods of assuming the turn and that the measures involved are relatively stable. It is also evident that the illusory effects occur at all levels of bank and are not transitory in nature even during the shallow banks.

Individual differences in the amount of apparent displacement observed during the turn were slight during the 10°, 18°, and 30° banks but increased sharply during the three steeper banks. Two of the

Ss observed the star move upward and remain displaced until the pilot began his recovery at which time the star returned to its original position. The third S frequently observed a return to the original 'true' position within a few seconds after reaching its maximum displacement. However, there were trials at all degrees of bank for this subject when he reported that the star did not return to the original position until the pilot began his recovery. For banks of 50° and 60° this S usually reported only a partial recovery to the 'true' position

TABLE II

PERCENT OCCURRENCE AND TEMPORAL RELATIONS OF MOTION AND DISPLACEMENT DURING THE BANKING OF THE AIRCRAFT

The lines marked C represent the data for the constant angle of attack, the lines marked V the variable angle of attack, and those marked VR represent the retest.

Angle of Bank		10°	18°	30°	40°	50°	60°
Frequency of motion	C	75%	95%	97%	100%	100%	100%
	V	78%	92%	97%	100%	100%	100%
	VR	—	78%	—	100%	—	100%
Frequency of displacement	C	28%	67%	75%	92%	97%	100%
	V	28%	56%	83%	100%	100%	100%
	VR	—	19%	—	89%	—	100%
Mean maximum vertical displacement in degrees	C	1.5	4.3	5.6	9.7	10.3	16.4
	V	2.5	4.8	8.9	12.1	23.3	27.5
	VR	—	1.1	—	7.5	—	22.1
Occurrence of motion in the direction of turn	C	42%	83%	86%	86%	95%	89%
	V	28%	56%	70%	61%	83%	92%
	VR	—	72%	—	95%	—	100%
Mean lag to first report of movement in sec.	C	16.0	8.7	8.5	6.9	7.0	7.1
	V	12.8	9.0	8.6	8.4	7.2	9.0
	VR	—	8.0	—	7.1	—	5.1
Mean total duration of illusory motion in sec.	C	10.8	22.7	20.7	24.4	26.2	30.2
	V	12.2	16.5	20.9	21.9	31.6	31.1
	VR	—	8.0	—	19.8	—	28.7

before the pilot began to resume straight and level flight. It is interesting to note that this effect was reported rarely during the series using a constant angle of attack and during the retests for this subject.

Table II also summarizes the data for the mean maximum displacement during the different degrees of bank. The average maximum displacement increased sharply with the angle of bank for all three series. An analysis of the data has shown that both the indidual differences and individual variability of the Ss are great. The differences between the mean scores are insignificant up to and in-

cluding the 40° banks. At 50° and 60° the amount of observed displacement was substantially more during the variable angle of attack series. Although this was true for all subjects, in no case did the difference reach the five percent level of significance. The mean scores were consistently less on retest than on the original series, but the differences were not statistically significant. The retest results at 60° suggest that there is a tendency toward reduction of the illusory displacement through experience. There also seems to be a slightly smaller effect during maneuvers with a constant angle of attack. However, this cannot be said with confidence because of the high variability of response.

The vertical motion and displacement observed during the bank and turn were complicated by reports of motion in the direction of turn during many of the trials (Table II). This involved either apparent motion to the right or left without displacement, or motion which was predominately upward but deflected to the right or left. The percent scores in Table II were determined by subtracting the number of reports opposite to the direction of turn from the number in the direction of turn and dividing by the total number of trials. It is evident that the probability of occurrence of this effect rises sharply as the angle of bank increases. This is true in all three series. It is also clear that the number of correct responses increases with practice.

The improvement in sensitivity in the perception of lateral motion also appears for two *S*s in thresholds (50 percent above chance) determined by linear interpolation. In the original series using the variable angle of attack subject C's threshold was 10° of bank. This rose slightly to 12° in the series using the constant angle of attack. G's threshold dropped sharply from 22° to 10°. M's threshold was equivocal for the first test but of the order of 30°. It showed a sharp drop to 12° on the second test. The general nature of the data indicated that his threshold would be approximately the same or perhaps slightly lower than during the constant angle of attack series. These results show a lowering of the threshold with successive series of observations. The difference between the accuracy of reports for the two methods of entering the turn cannot, therefore, be attributed to a difference in the stimulus situation. This latter result might be expected since the stimulus (angular acceleration) to the horizontal canals is nearly identical in the two situations (Table I).

The data for the lag from the beginning of the bank (A) to the first report of movement of whatever type are summarized in Table II. It is important to remember that this lag is a time interval from the beginning of the maneuver, but not necessarily the beginning of a change in the stimulus situation. This is true because there is a lag

in time from the beginning of the bank to the change in direction of flight, due to the inertia of the plane. The results show a decrease in lag as the angle of bank increases. The individual variability tended to become slightly less also. There were no consistent differences between the two situations.

The total duration of apparent movement reported during the bank increased sharply with the angle of bank (Table II). The duration of the observed motion during the 60° banks was nearly three times that observed during the 10° banks. There was no significant difference between the three test situations.

There was considerable variability between the three *S*s in reports of the apparent rotation of the star in the plane of its radiating lines. This was particularly true during the first series of tests using the variable angle of attack. One *S* (G) showed little variation in the number of reports of rotation in each series. On the other hand the other two *S*s showed a progressive increase in the occurrence of this illusion of rotation on the successive series. The original reports were too meager to exhibit a relation between the effect and the degree of bank, but on the retests the percent occurrence increased directly with the angle of bank. This phenomenon was very difficult to report because of the complexity of the task, because the maximum rotation was small, and because the maximum effect frequently occurred suddenly without any apparent intervening motion. It has been studied in isolation and will be described in detail in another paper.

2. *Illusory effects observed during and after recovery from the turn.*—These effects in all three series were essentially the reverse of those observed while assuming and during the bank. During the trials in which one *S* saw the star return to the 'true' position prior to the beginning of the recovery, the star moved or was displaced downward. This was followed by recovery to the egocentrically 'true' position. In the remaining trials the three *S*s observed either motion alone or motion and displacement downward to the 'true' position.

The time relationships between the beginning of the recovery to straight and level flight and the subsequent illusory effects are shown in Table III. Some entries, as noted in Table III, are for only two *S*s, since the third observed a type of recovery which was characteristically different from the other two. It is evident that the average lag to the first movement opposed to the original motion decreased gradually as the angle of bank increased. Here again there is no clear relation between the angle of bank and the time for recovery to the initial true position without further movement or to the time to come to zero displacement. There was no significant difference between the three test situations.

It is evident (Table III) that the duration of illusory movement reported during and following recovery increases sharply with the angle of bank. Individual variations were present but the increase is clear for all three test situations. The differences between the results, though not significant statistically, are consistently in favor of more reported movement in the series using a constant angle of attack. The fact that the recovery times are also consistently longer is a factor here.

TABLE III

TIME RELATIONS FOR ILLUSORY EFFECTS IN SEC. FROM THE BEGINNING OF THE RECOVERY FROM THE BANKS (C)

The lines marked C are for the constant angle of attack, the lines marked V for the original series using a variable angle of attack, and the items marked VR for the retest.

Angle of Bank		10°	18°	30°	40°	50°	60°
Av. lag from C to the first opposed movement; S = 2	C	6.2	5.8	4.5	3.7	3.6	3.6
	V	8.0	5.5	4.8	4.2	3.3	3.1
	VR	—	6.1	—	4.8	—	3.8
Av. time to recover zero displacement from C; S = 2	C	16.2	16.5	14.6	14.8	14.5	17.3
	V	12.5	17.0	16.3	15.9	20.5	17.9
	VR	—	22.5	—	17.4	—	21.4
Av. time from C to final recovery to 'true' position; S = 2	C	16.6	22.3	25.3	27.6	28.1	27.0
	V	21.5	25.6	24.4	25.5	26.4	28.6
	VR	—	19.2	—	22.9	—	26.8
Av. duration of reported movement; S = 3	C	14.1	19.5	21.6	28.8	25.9	29.2
	V	10.6	15.3	19.0	24.4	24.9	25.8
	VR	—	10.7	—	18.2	—	25.1

For two of the Ss the illusory effects during and following recovery were principally in the vertical plane. However, one *S* regularly reported movement in the direction of 5 or 7 o'clock. Practically all of these reports were opposite to the direction of the previous turn. There was no statistical difference between these data and those found for this *S* as the pilot entered the turn. The *S*'s threshold 50 percent above chance was 10° in the variable angle of attack series and 13° in the constant series by linear interpolation. These are very close to those found in his data on entering the bank. This would be expected since the angular acceleration (Table I) is practically identical in the two cases. This *S* also periodically reported motion opposite to the direction of turn following recovery to zero displacement. These movements were appropriate in each case, i.e., opposite to the direction of turn.

DISCUSSION

These illusory movements and displacements observed in flight may be considered as a resultant of the complex effects of the forces

of acceleration on the *S*. Stimulation of the otolith organs by centrifugal force and stimulation of the semicircular canals by angular acceleration are the principal factors isolated here. Autokinesis, feelings of rotation and increased bodily pressure are also present and may be important. The factors producing the total perception cannot be isolated with the precision necessary to identify with confidence the discrete stimulus-response relationships and the mediating sensory organs. Therefore, it is not possible to state with certainty which aspects of these effects could be classified as the results of semicircular canal stimulation by angular acceleration, which parts are the result of stimulation of the otolith organs by centrifugal force, and what influence increased feelings of bodily pressure and feelings of rotation contribute. However, these data and those obtained in the laboratory (**3, 4, 5**) support the hypothesis that the stimulus to the semicircular canals was often effective alone and in some cases was followed by and combined with the effects of stimulation of the otolith organs.

Laboratory studies (**3, 4, 5**) have suggested that when the effects of of angular acceleration and centrifugal force are separated and controlled, illusory phenomena similar to those observed in flight occur. Three specific illusory phenomena have been described in this experiment: 1. Vertical displacements were observed at the onset of and during the turn. These displacements are considered to be examples of the oculo-gravic illusion resulting from changes in centrifugal force. This illusion is produced in the laboratory when the *S*s, seated in a centrifuge, are subjected to centrifugal force which produces an increased resultant force acting at an angle to the *S*'s vertical (**5**). 2. Lateral motion was observed toward three or nine o'clock or superimposed on the upward displacement. This may be considered to be an example of the oculo-gyral illusion resulting from the angular acceleration during the turn. It is obtained in the laboratory when an *S* is subjected to angular acceleration which causes a nystagmus which in turn leads to the perception of motion (without displacement) of a fixed object (**4**). 3. Rotation of the test object was observed in some trials. This effect seems to depend upon the stimulation of the semicircular canals and will be described in detail in a separate report.

These hypotheses are supported by the following considerations: The oculo-gyral and oculo-gravic illusions, as here identified, appeared both together and separately. The apparent motion to the right or left had the typical characteristics of the oculo-gyral illusion in that no clear displacement was observed in the direction of movement and that the effect disappeared within a few seconds. The vertical dis-

placements, on the other hand, persisted for the duration of the centrifugal force.

Reporting these illusory effects was a highly complex task which was accomplished only after much practice. In spite of the fact that the *Ss* had had considerable experience in reporting these phenomena, rotation and displacement of substantial amounts were sometimes reported as appearing suddenly without preceding motion. Such reports may have resulted from a restructuring of the field following sub-threshold stimulation or may have resulted from a sudden shift of attention. It appears likely that both of these actually occurred.

Throughout this report the stimulus situation has been described in terms of the angle of bank of the aircraft. The specific stimuli, however, were centrifugal force and angular acceleration. These stimuli were not used as a basis for the discussion since adequate devices were not present in the plane to measure them directly. Estimates of the angular acceleration were determined from the data showing the amount of time required to assume a turning attitude and the rate of turn. The resultant forces can be estimated readily, since the 'g' is equal to the secant of the angle of bank. Gain or loss of altitude and deviations from the true angle of bank will cause substantial variations in the stimulus situation. These facts make it difficult to determine precise stimulus-response relationships; for example there was an apparent increase in the feelings of bodily weight several seconds after the plane had assumed the maximum bank and therefore several seconds after the maximum 'g' was theoretically operative. It cannot be said with confidence whether this effect is due to changes in the forces on the aircraft or to a lag in the sensory effects.

The marked individual differences between the *Ss* are worth noting and raise important theoretical questions. These differences are by far the most marked during the 40°, 50°, and 60° banks. The three *Ss* had had approximately equal experience in observing the phenomena in the air, but the one who reported the smallest displacements and recovery during the bank had had extensive experience in observing these effects on a human centrifuge. This suggests the importance of habituation in this situation. There is ample experimental evidence that nystagmus and other associated phenomena tend to diminish with successive exposures to angular acceleration (**1, 7, 8**). There is also considerable evidence from dancers and sailors as well as flyers that this habituation does occur. No previous studies have been made of habituation to the effects of 'g' on visual perception. The fact that marked habituation was not observed may be a result of the short periods of stimulation and the relatively long periods of time between trials.

These results have important implications for flying particularly during night operations and instrument flights when visual cues are meager or lacking. Confusions under such conditions do occur and angular acceleration and centrifugal force can contribute to confusions in pilots flying at night.

Summary

The oculo-gyral and oculo-gravic illusions were studied in flight using three Ss who observed a fixed luminous target in the dark. The observations were made in the rear cockpit of an SNJ-6 aircraft while the pilot executed turns with different degrees of bank. The chief purposes of the study were: (1) to compare the illusions observed during two methods of executing a turn, (2) to determine the occurrence of the illusions in terms of both angular acceleration and centrifugal force, and (3) to determine whether habituation occurred during the experiment. In the first series the turns were carried out by using a constant power setting and changing the angle of attack of the wing to maintain the proper altitude. In the second series the angle of attack was held constant while the power was increased to maintain altitude. The third series was a repetition of the first for three selected angles of bank.

There was no consistent difference in the pattern of illusory response observed in the three series. This was true of the amount of illusory motion and displacement, the time relations, and the sequence of events. Therefore, there was no significant evidence of any difference in the illusory perceptions during the two types of banks nor was there evidence of habituation within the limits of this experiment. The illusory motion and displacement upward occurred at all angles of bank studied. There was a clear positive relation between the accelerative forces and the occurrence of the illusions. There was also an increase in the magnitude and duration of the illusions observed as the accelerative forces increased.

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References

1. Dodge, R. Habituation to rotation. *J. exp. Psychol.*, 1923, **6**, 1–35.
2. Graybiel, A., & Clark, B. The autokinetic illusion and its significance in night flying. *J. aviat. Med.*, 1945, **16**, 111–151.
3. Graybiel, A., & Hupp, D. I. The oculo-gyral illusion: a form of apparent motion which may be observed following stimulation of the semicircular canals. *J. aviat. Med.*, 1946, **17**, 3–27.
4. Graybiel, A., Clark, B., MacCorquodale, K., & Hupp, D. I. The role of vestibular nystagmus in the visual perception of a moving target in the dark. *Am. J. Psychol.*, 1946, **59**, 259–266.

5. GRAYBIEL, A., HUPP, D. I., & PATTERSON, J. L., JR. The law of the otolith organ. *Fed. Proc.*, 1946, **5**, 35.
6. GRAYBIEL, A., CLARK, B., & MACCORQUODALE, K. The illusory perception of movement caused by angular acceleration and centrifugal force during flight. I. Methodology and preliminary results. *J. exp. Psychol.*, 1947, **37**, 170–177.
7. GRIFFITH, C. R. The organic effects of repeated bodily rotation. *J. exp. Psychol.*, 1920, **3**, 15–46.
8. HOLSOPPLE, J. Q. An explanation for the unequal reductions in post-rotation nystagmus following rotation practice in one direction only. *J. comp. Psychol.*, 1924, **4**, 185–193.
9. KERR, W. A., & GRAYBIEL, A. Thresholds of stimulation of the horizontal semicircular canals in man. *Amer. Psychologist*, 1946, **1**, 237–238.
10. MULFORD, W. P. C. Case of vertigo. *Bur. Med. News Letter* (Aviation Suppl.), 1945, **5**, 6.
11. VINACKE, W. E. Types of illusions experienced by aircraft pilots. *Amer. Psychologist*, 1946, **1**, 282.

BRIGHTNESS CONSTANCY AND THE NATURE OF ACHROMATIC COLORS

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PART I

The problem of brightness constancy arises through the following circumstances. The amount of light which is reflected by an opaque object and which stimulates the eye depends not only upon the color of the object but just as much upon the amount of light which falls on the object, that is upon the illumination in which the object is seen. When in spite of this, the seen colors are in agreement with the object colors, when a given object appears to have the same color in various illuminations, we speak of brightness constancy.

The majority of investigators who aim at all at functional explanations understand this problem to mean: How is illumination registered and in what way is it taken into account so that the experienced colors remain constant when the illumination is varied? In this version the problem is a difficult one at the outset, for illumination is never directly or independently given but is represented in stimulation only in as much as it affects the amount of light which is reflected by the objects. To be sure, we perceive illumination as well as surface color; a spot of light here, a shadow there, a brightly lighted region near the window or the dim light of dusk on everything. But the fact remains that both variables, object color and objective illumination, affect the eye through the same medium, the varying amount of reflected light. If the seen illumination were found to be in agreement with the objective illumination, in principle the same problem would arise which we face regarding the surface colors. There is only one stimulus variable to represent two objective variables each of which seems to have its counterpart in experience. Under these circumstances investigation has largely consisted in the study of factors by which illumination could be recognized and in the demonstration of their effectiveness in bringing about constancy.

The following observations suggested a radically different approach to the writer. They concern some variations of an experiment by A. Gelb which demonstrated brightness constancy in a most impressive way. Gelb's experiment [1] is most conveniently performed

[1] Described in W. D. Ellis, *A source book of gestalt psychology*. New York: Harcourt, Brace, 1939, p. 207.

by opening the door of a dimly lighted room and by suspending in the frame a piece of black paper. This paper is illuminated by a strong projection lantern which stands on the floor or on a low table and is tilted upwards so that the part of its beam which is not intercepted by the black paper passes through the open door onto the ceiling of the adjacent room where it is invisible to the observer. In the light of the strong lantern the paper may look white instead of black. When a white piece of paper is held up in front of the black paper so that it too reflects the strong light of the lantern, the black paper assumes a black color. According to the usual interpretation it looks first white because no cues for the special strong illumination are available when this illumination affects only one visible surface. With the introduction of the white paper into the beam a special brilliant illumination becomes visible and constancy is restored: the two papers are perceived with their real color.

The arrangement of Gelb's experiment lends itself to a still more impressive demonstration. When the black paper is presented alone, reducing the intensity of the lantern light by small steps to zero causes the perceived color of the paper to vary all the way from white through gray to black. Every change in illumination is accompanied by a corresponding change in the perceived color. However, when a larger white paper is fastened behind the black paper so that the latter is seen surrounded by white, the same changes in illumination do not at all affect the seen colors which remain white and black throughout. Paired in this way the colors are immune to changes in illumination and remain 'constant.' It is rather a change in the perceived illumination which now accompanies the change in the objective illumination.

The question arises: what determines the color with which the black paper is seen at a given intensity of the lantern light when the paper is presented alone? Do we deal in this situation with an absolute relation between the intensity of the light which stimulates a portion of the retina and the resulting perceived color? In considering this question we have to remember that there is another variable in the situation, the dim general illumination of the room. When this is varied it becomes immediatley clear that this general illumination also affects the color of the black paper. When, with a high intensity of the lantern light, the general illumination is raised, the color of the black paper changes from white to gray, and this in spite of the fact that the paper too now reflects light of a somewhat higher intensity than before. Only *relatively*, that is in relation to the light which comes from other surfaces, has the light reflected by the black paper become less intense.

Such dependence of the perceived color on the *relative* intensity of the perceived light should be demonstrable in a much simpler form, and this is the case.

In a dark room a white screen is illuminated by the light of two slide projectors. In one of the projectors an opaque card with a circular hole of ½ in. diameter is inserted, and the bright image of the hole is focused on the screen. The slide for the other projector consists of a blank glass covered with an opaque card with a circular hole of one in. diameter and with a ½ in. cardboard disk which is pasted concentrically into the hole. Focused on the screen this slide produces a bright ring. The two projectors are so adjusted that this ring surrounds the image of the ½ in. hole so that the edge of the latter coincides with the inner edge of the ring. The light intensity of the projectors can be changed by running them on variable transformers or by letting their beams pass through episcotisters.

We have then on the screen a circular region (disk) and surrounding it a ringshaped region which reflect light intensities that can be separately controlled. When the intensity of the disk is kept constant and that of the ring is widely varied, the color of the disk may change all the way from white to dark gray. The disk looks dark gray when the light reflected from the ring is of high intensity and it becomes white when the brightness of the ring is greatly lowered. When the light intensity of the disk is varied and that of the ring is kept constant, the color of the disk, of course, undergoes similar changes. Again it is quite clear that the color which appears in one region, namely in that of the disk, depends on the relation of the light intensity of this region to that of its surroundings. This is true also of the ring. It can be shown in corresponding fashion that its color depends on the relation of the intensity of the ring to that of the disk.

When the ring is altogether omitted so that the disk is seen in completely dark surroundings, it ceases to look white or gray and assumes instead a luminous appearance similar to that of the moon at dusk. Lowering the intensity of the disk greatly does not change this mode of appearance, provided the rest of the room is really dark; the disk looks merely dimmer. The same observation can be made with the ring when it is presented without the disk, or with both the ring and the disk when they are placed far from each other on the screen. Opaque colors which deserve to be called white or gray, in other words 'surface colors,' will make their appearance only when two regions of different light intensity are in contact with each other, for instance when the ring surrounds the disk or when two oblongs have the longer edges as their common border.

The importance of a close contact for the emergence of surface colors becomes strikingly clear in the following observation. The intensity of the disk is adjusted to be one quarter that of the ring, which makes the color of the disk a medium gray. An opaque object is moved from the side into the beam of the lantern which projects the ring so that part of it is blotted out by the shadow of that object.

When this happens the gray color disappears almost simultaneously from that part of the disk which is adjacent to the shadow. It looks as if the dense gray there were dissolving leaving the screen transparent to let a light behind it shine through. Brought about in this fashion, the change from surface color to a luminous appearance is quite impressive. That side of the disk which is still well surrounded by a brighter ring continues to show the gray color, and between it and the luminous side the disk shows a steady gradient in the density of the gray.

These observations make it clear that, at least under these conditions, surface colors occur in our experience when regions of different light intensity are in contact with each other and that the particular surface colors which come about depend on the relation of these light intensities. They are apparently the product of nervous processes of limited scope, for close spatial contact between the regions of different light intensity is required for their emergence. Moreover, the degree to which surface color is present in a certain region depends on the intimacy of the contact between this region and its partner. This is easily demonstrated by the following observations.

No matter what the brightness relation between ring and disk be, the ring will always show a less dense surface color and have more of a luminous appearance than the disk. This becomes quite clear when two pairs of such regions are presented for comparison which are so chosen that the intensity of the ring in one pair equals that of the disk in the other one, and vice versa. Even the region of lower light intensity in each pair, which is perceived as a gray, has a more luminous appearance where it occurs in the ring than where it occurs in the disk. The most obvious explanation for this difference in the mode of appearance is that the disk is more under the influence of the ring than vice versa, in as much as the disk is completely surrounded by the ring, whereas the ring is in contact with the disk only on one side. This explanation agrees well with the observation reported earlier that the elimination of part of the ring rendered that part of the disk more luminous which was then no longer enclosed by a region of different light intensity.

This influence under which surface colors emerge is clearly a mutual one. Though less so, the ring does display surface color. There is a great difference in the mode of appearance between a ring which surrounds, for instance, an area of higher intensity and an equal ring presented in an otherwise dark field. Whereas the latter looks merely luminous, the former shows in addition to some luminousity a distinct gray.

The mutual influence on which the emergence of surface colors depends must also account for the fact that the particular colors

which come about depend on the relation of the stimulating light intensities. It is probably best conceived of as some kind of interaction which takes place as part of the nervous process which underlies color perception.

It will be remembered that the dependence of the perceived colors on the relative intensities of the stimulating light was also evident in the variations of Gelb's experiment which were first reported. It remains to be added that the transition from surface color to a luminous mode of appearance can be demonstrated with Gelb's set-up in the following way. At first the special illumination of the black paper and the general illumination of the room are so adjusted that the black paper looks white. When now the general illumination is further reduced, the paper becomes more and more luminous, and it ceases altogether to look white when the rest of the room is completely dark. Luminosity of the paper can also be produced by excluding the general illumination from its immediate neighborhood. By such measures a rather luminous gray, not unlike that appearing in the ring, may also be achieved. Thus it is not only in projected rings and disks that luminosity appears as an alternative to surface colors when adequate differences in intensity are lacking or when the contact between those regions is diminished. Clearly discernible segregated objects as for instance a suspended piece of black paper function in the same fashion.

Part II

So far, we have become acquainted with the way in which surface colors come into existence and with the manner in which they depend on the stimulus situation. They depend on the relation of stimulus intensities on the retina which are so located with regard to each other that the subsequent nervous processes interact. Now the question arises what bearing this has on the problem of brightness constancy.

In order to answer this question, some clarification of the nature of brightness constancy is needed. One may say that brightness constancy prevails when a perceived color is in agreement with the corresponding object color. Object color is a persistent physical characteristic of a surface, the property to reflect a certain proportion of the light which falls on that surface. For instance, a surface which looks black under constancy conditions reflects about four percent of the illuminating light, and a white one about 80 percent. This property, called reflectance, is not conveyed to the eye as such. It is rather represented to the eye by light of a given intensity. This fact constitutes the problem of brightness constancy, for the intensity of the reflected light depends to the same degree on the color of the reflecting surface as on the strength of the illumination. If in our environment illumination were always and everywhere the same, the fact that our visual sense is not directly affected by reflectances but only by the reflected light intensities would not raise a problem in perception, for

the reflected light could represent the object colors unequivocally. But illumination varies widely, even between different parts of the same visual field, and often very different light intensities come to represent the same reflectance to the eye and, in constancy, produce the same color in the observer's experience. When, for instance, a medium gray which reflects 20 percent of the illuminating light is presented once in an illumination of an intensity 100 and again under light of an intensity 300, the intensities of the reflected light are 20 and 60 respectively; if complete constancy prevails, both stimulus intensities lead to perception of the same medium gray. Similarly the white background on which the gray samples are shown will reflect light of the intensity 80 in the weaker illumination and of the intensity 240 where it is in the stronger illumination, and the two differently illuminated parts of the background will probably both be judged as white. At first glance no orderly connection between stimulus intensity and perceived color seems to exist.

There is, however, one feature in the stimulus situation which remains the same when the illumination is varied. The intensity of the light reflected by the gray in the weaker illumination (20) stands in a ratio of 1:4 to that reflected by the white in the weaker illumination (80), and the same ratio exists between the intensities reflected by the gray and the white in the stronger illumination (60 and 240). It is easy to see that in the case of any given set of object colors the *ratios* of the intensities of the reflected light remain the same for any change in illumination which affects all of them.[2] Thus, if the perceived colors were to depend on the *ratios* of the intensities of the reflected lights, they would remain unchanged when a given set of object colors were presented in changed illumination, and constancy would be assured. A medium gray may serve again as an example. Although it affects the eye with different light intensities when the illumination is changed, it would be perceived as the same color because the ratio of the intensity that it reflects to the intensity of the light reflected by the surrounding white would remain the same, for a change in illumination affects the latter in the same proportion.

At this point we have to consider the observations reported in Part I. They suggested that the perceived surface colors depend on the relation, not yet quantitatively defined, of the light intensities in interacting regions. But we now find that constancy would result, if our visual perception functioned in such a fashion that the perceived colors depended on the *ratios* of the intensities of the reflected light.

Thus, we merely have to make the assumption that the relation on which surface colors depend is one of simple proportionality to give the observations of Part I a direct bearing on the problem of brightness constancy. If this assumption were correct brightness constancy would find its explanation in the very process by which surface colors come about.

[2] This is a simple consequence of the fact already mentioned that object colors reflect a constant *fraction* of the illumination.

This assumption can be tested by simple experiments. If it is correct, the particular colors which are perceived in a pair of ring and disk should depend on the ratio of the intensities of the two regions, and only on that ratio. In other words, no matter what the absolute intensities of ring and disk may be, the same colors should be seen in the case of any pair of intensities which happen to stand in the same ratio to each other. This is, in close approximation, the case, as the following report of quantitative experiments [3] shows.

Two pairs of ring and disk were used, in order to permit simultaneous comparison. The intensity of each of these four regions could be varied independently.

Four identical projections lanterns equipped with 500 watt bulbs were used for this purpose. They were arranged in two groups and each group produced on the screen a pair of ring and disk as described in Part I. They were all so adjusted that they gave their respective regions the same light intensity. This was done in the following way. First a pair of ring and disk was formed with one lantern from group I and one from group II, and the intensity of one of them was varied until the contour between the ring and the disk disappeared because of brightness equality. Then these two lanterns were restored to their respective groups and similar adjustments were made within each group by varying the light intensities of the not yet equated lanterns.

The intensity variations required by the experiments were brought about with the help of episcotisters through which the lantern beams had to pass before reaching the screen. This technique has the advantage that the episcotister apertures are a direct measure of the relative intensities in the various regions.

Measurements were made by the method of limits. Ring and disk of one pair and the ring of the other pair were kept at constant intensities, and the intensity of the remaining disk was varied in suitable steps until the *S* judged the colors of the two disks as equal.

In the first experiment one of the rings was given the full illumination of its lantern and the disk inside it received half of the intensity, for its light beam passed through an episocotister of 180 degrees aperture. The light for the ring of the other pair was cut down to one-eighth of full intensity by passing it through an episcotister of 45 degrees aperture. The aperture for the disk of the latter pair was varied in steps of two degrees. The following are the means of one upper and one lower limit for each of five *S*s: 24, 26, 24, 23, 24 degrees with a total mean of 24.2 degrees. This result means that, on the average, a light intensity in a disk corresponding to an episcotister aperture of 24.2 degrees when it is surrounded by a ring of an intensity of 45 degrees aperture brings about in the *S*'s experience the same gray as does a disk of an intensity of 180 degrees aperture inside a ring of an intensity of 360 degrees aperture. There is only a small deviation from the value of 22.5 degrees which with 45 degrees forms the same ratio as does 180 degrees with 360 degrees. Comparing the grays in the two disks was not difficult for the *S*s. The great difference in absolute intensity between the two pairs of ring and disk (8:1)

[3] These experiments were performed by the students of various seminars in Perception and classes in Experimental Psychology at Swarthmore College under the author's supervision.

made the less intense pair look much dimmer, but that did not affect the distinctness of the disks' color. However, it made the rings look very different; though both were white, the more intense one was by far more luminous. This latter observation which was also made in most of the following experiments seems to be important, for it corresponds to a fact which can be observed in real constancy situations. When identical sets of object colors are placed in different illuminations and appear approximately the same, the set in the stronger objective illumination is often also *seen* to be more strongly illuminated. Perceived illumination and the different degree of luminous appearance which was frequently observed in our experiments seem, functionally speaking, to be closely related experiences. A detailed discussion will be presented in a later publication.

In another experiment a disk of 90 degrees intensity was shown in a ring of 360 degrees intensity. This combination which forms an intensity ratio of 4:1 brings about a much darker gray in the disk. In the other pair, the disk whose intensity was varied was surrounded by a ring of 180 degrees intensity. The proportionate value for the disk is here 45 degrees. The averages of two upper and two lower limits for each of four *S*s were 46, 52, 45, 44 degrees with a mean of 47 degrees.

In the following experiment the disk of the brighter pair was varied and a ratio of 3:1 between ring and disk was used. In the darker pair, the ring had an intensity of 180 degrees and the ring one of 60 degrees, and the variable disk was surrounded by a ring of 360 degrees intensity. Five upper and five lower limits were determined for each of three *S*s. The means were 113, 115, 121 degrees. The proportionate value is here 120 degrees.

It will be noted that so far all deviations from the proportionate values were in one direction. They all imply that, where they occur, a disk of proportionate intensity in the dimmer pair looks darker than the disk in the pair of higher intensity; *viz.*, in the first two experiments the disk in the less intense pair had to be given a slightly higher than proportionate intensity to give a color match and in the last experiment the disk in the more intense pair had to be made objectively darker. Thus, although these deviations are small, they deserve our attention. Experiments with an improved technique were made to find out how significant they are.

To facilitate measuring a variable episcotister [4] was used for the determination of the limits. This device permits changing the aperture by definite amounts while it is spinning. Only when the *S*s had given a judgment of equality was the episcotister stopped and its angle measured with a protractor.

It has been described above how the intensities of the four lanterns were equated at the outset of the experiments. These equations are likely to contain subliminal errors which could

[4] Designed and built by R. Gerbrands, Emerson Hall, Cambridge, Mass.

affect our measurements. In the experiments which follow the episcotisters were interchanged between the groups of lanterns after half the number of limits had been determined for a given *S*, so that the group which during the first half of an experiment produced the brighter pair of ring and disk were made to produce the dimmer pair during the second half, and vice versa. Thus, any error in the original lantern adjustment which would affect the measurements during the first half of the experiment in one direction would in the second half affect it in the opposite direction. In this manner such an error will appear in the scatter of the limit values but will not affect their mean.

The first experiment (I) done with this improved technique was one with a small difference between the brighter and the dimmer pair. The former had a ring of 360 degrees intensity and a disk of 180 degrees, and the other pair had a variable disk in a ring of 180 degrees. Four *S*s took part in the experiment. For each one four upper and four lower limits were determined. Table I presents the means of these limits. The proportionate value is here 90 degrees. It will be noted that the small deviations from this value are in a direction opposite to those previously reported, for they would imply that a disk of proportionate intensity in the dimmer pair is perceived as a slightly lighter gray than the disk in the more intense pair.

TABLE I

EPISCOTISTER SETTINGS IN DEGREES FOR DISK WITHIN RING OF 180 DEGREES IN COMPARISON WITH DISK OF 180 DEGREES WITHIN RING OF 360 DEGREES

Subjects	Ad.	McN.	Ba.	Cl.	
Upper limit	88	86	85.5	90	
Lower limit	84	84	79.5	84.5	
Mean	86	85	82	86	Grand mean: 85

TABLE II

EPISCOTISTER SETTINGS IN DEGREES FOR DISK WITHIN RING OF 90 DEGREES IN COMPARISON WITH DISK OF 240 DEGREES WITHIN RING OF 360 DEGREES

Subjects	Mo.	Cr.	Ke.	Cy.	
Upper limit	61	62	73	74	
Lower limit	62	64	68	67	
Mean	61.5	63	70.5	70.5	Grand mean: 66.4

This is not so with the results of the following experiment (II) in which a still lighter gray was produced and in which the intensity of the dimmer ring was only one quarter of that of the brighter one. In the dimmer pair the ring had an intensity of 90 degrees and the disk was variable, while in the brighter pair the ring had 360 degrees and the disk 240 degrees of light. The results are given in Table II. With the *S*s Mo. and Cr., 10 upper and 10 lower limits were determined, with Ke. and Cy. only six. Individual differences are larger in this experiment. For two of the *S*s there was a marked deviation

from the proportionate value of 60 degrees, which implied that for them a disk of 60 degrees intensity in the dimmer pair showed a slightly darker gray than the disk in the brighter pair.

Ten Ss were employed in an experiment (III) in which the variable disk was surrounded by a ring of 360 degrees of light and the dimmer pair consisted of a ring of 90 degrees and a disk of 30 degrees intensity. Six upper and lower limits were determined for each S, except for Ss Mo. and Cr., who again supplied 10 pairs of limits each. The average of the individual means as shown in Table III was 106 degrees, a clear deviation from the proportionate value of 120 degrees. It implies that the gray in the disk of low intensity looks somewhat darker than a disk of proportionate value in the brighter pair.

TABLE III

EPISCOTISTER SETTINGS IN DEGREES FOR DISK WITHIN RING OF 360 DEGREES IN COMPARISON WITH DISK OF 30 DEGREES WITHIN RING OF 90 DEGREES

Subjects	Ca.	Ga.	Hs.	Ht.	Lu.	Ro.	Mo.	Cr.	Ke.	Cy.	
Upper limit	104.5	91	117.5	116.5	113	130	128	107.5	105	113	
Lower limit	92.5	91	99.5	98.5	103	112	100	103	97	95	
Mean	98.5	91	108.5	107.5	108	121	114	105	101	104	Grand mean: 106

The direction of the deviations from proportionate values encountered in the last two experiments was such that they could be regarded as the effect of a slight influence of the absolute stimulus intensities on the color process which otherwise could be conceived as functioning according to a proportional law. The question arose whether these deviations reflected intrinsic properties of the color process or whether they were introduced by incidential experimental conditions. An answer cannot yet be given and must be left to further detailed investigation. However, an experiment which was performed with this question in mind will be reported below, because it will add the data of still another combination of intensities.

It was suspected that the presence of the brighter pair of ring and disk in the visual field when the gray in the disk of the dimmer pair developed was responsible for the fact that this gray looked a trifle too dark. If the high intensities of the brighter pair had an influence across the spatial interval on the colors which emerged in the dimmer pair, this is what should have happened. Such an influence can be avoided by presenting the pairs successively. This was done in the following experiment (IV). The intensities in the brighter pair were 360 and 180 degrees, the ring in the dimmer pair was 90 degrees and the disk was varied. Table IV shows for four Ss the means of four upper and four lower limits. Ordinarily, with an intensity ratio of 4:1 between the rings the deviation under discussion was to be

expected. It did not appear. The slight deviation from the proportionate value of 45 degrees was in the opposite direction.

In another experiment, however, successive presentation failed to eliminate completely the deviation under discussion. Experiment III was repeated with three further *S*s who did the experiment twice, once with successive and once with simultaneous presentation. The limits listed in Table V are the averages of four determinations each. Although successive presentation reduces the deviation from the proportionate value of 120 degrees, it does not eliminate it.

TABLE IV

EPISCOTISTER SETTINGS IN DEGREES FOR DISK WITHIN RING OF 90 DEGREES IN COMPARISON WITH DISK OF 180 DEGREES WITHIN RING OF 360 DEGREES

Subjects	Ad.	McN.	Ba.	Cl.	
Upper limit	43	42	41	44	
Lower limit	41	40	42	44	
Mean	42	41	41.5	44	Grand mean: 42

TABLE V

EPISCOTISTER SETTINGS IN DEGREES FOR DISK WITHIN RING OF 360 DEGREES IN COMPARISON WITH DISK OF 30 DEGREES WITHIN RING OF 90 DEGREES

Subjects Presentation	Cl.		He.		Be.	
	Sim.	Succ.	Sim.	Succ.	Sim.	Succ.
Upper limit	110.5	121	99	108.5	104	112
Lower limit	99.5	99	97.5	99	94	104
Mean	105	110	98	104	99	108

These deviations from proportionate values appear rather insignificant when one compares them with the remaining effect of the proportional law. For example, in experiment III which showed the largest deviation, a disk of an intensity of 30 degrees aperture had on the average the same color as one of an intensity of 106 degrees aperture, that is, an intensity 3.5 times as high. The deviation from the proportionate value of 120 degrees amounts only to 12 percent.

It should be mentioned at this point that such experiments can also be done with a less elaborate set-up. Two color mixers and one projection lantern suffice for a crude demonstration of the proportional law. With the help of a large color wheel of black and white disks and a small one fastened on top of it to the same mixer one can obtain a ring-shaped and a circular region in which the intensities of the reflected light can be varied independently. On one mixer, e.g., the large wheel can be set to show a sector of 90 degrees white and the small one a sector of 45 degrees white. To the other mixer are fastened a small wheel with a white sector of 180

degrees and a large wheel of 360 degrees white. When the mixers spin in general room illumination, one sees a dark gray disk surrounded by a medium gray ring on one mixer and a light gray disk in a white ring on the other one. However, when the mixers are placed in separate strictly local illumination they look quite different. That illumination can be provided by a lantern equipped with an opaque slide which has two circular holes a good distance apart. It projects two narrow beams of light of equal intensity. When the mixers are placed each in one of the beams at such a distance from the projector that their wheels are covered by the light almost to the outer rim and the rest of the room is entirely dark, both color mixers show a white ring and a light gray disk much alike in color. The reason for this change is easy to understand. Under local illumination the two color mixers provide exactly the same pattern of stimulus intensities as the set-up in experiment IV, and thus the same colors develop as in that experiment. In general illumination, on the other hand, the pairs of ring and disk are surrounded by regions of other intensity, e.g., the light reflected by the wall of the room, which cooperate in determining the colors which come about in the pairs. If, for instance, light reflected by a white wall forms the stimulus intensity of the surrounding region, that intensity stands to the intensity of the dimmer ring in a ratio of 4:1, and in this relation the ring should assume a medium gray color, as indeed it did.

It was explained above how the assumption that the achromatic colors depend on the ratios of the pertinent stimulus intensities accounts for brightness constancy. On that occasion complete constancy was shown to follow from this assumption. However, complete constancy has hardly ever been demonstrated experimentally. An object color presented in reduced illumination usually looks somewhat darker than another sample of that color in full illumination, though not as much darker as the difference of the reflected light intensities would warrant if there were no constancy. Yet complete constancy would follow from a direct application of the proportional law. Deviations from proportionality which occurred in our experiments are by far too small to account for the usual lag in constancy. The difficulty resolves itself when it is realized that the proportional law cannot be applied so simply to this situation. Here the two pairs of regions, the sample and its background in full illumination and the other sample with background in reduced illumination, are not as completely separated from each other as the corresponding regions in our experiments, for the regions of different illumination are in contact with each other and the brighter one can have an influence on the dimmer one. In other words, we have here a case where three or more regions of different intensity interact. Such processes have not yet been sufficiently investigated, and no report can be made at this time. It seems, however, quite likely that a full investigation will furnish the rules for the prediction of the lag in constancy in individual experiments.

This report may so far have given the impression that, apart from the small deviations discussed, the proportional law permits prediction of color equations if the pertinent stimulus intensities are known.

However, this is so only with important qualifications. To a certain extent also the geometrical arrangement of the regions of different intensity has an influence on what colors come about in these regions. Some brief experiments which permit a first appraisal of the importance of these conditions will be reported below.

In the measuring experiments so far reported the width of the ring was $\frac{5}{8}$ of the diameter of the disk so that the area of the ring was four times as large as the area of the disk. A reduction of the width of the ring to $\frac{1}{4}$ of the diameter of the disk so that its area was about the same as that of the disk did not affect the color in the disk as the following experiment shows, in which the colors in two disks were compared which were surrounded by rings of different width. Both rings were given the same intensity of 120 degrees aperture; the disk in the narrow ring had an intensity of 15 degrees and appeared as a very dark gray; the disk in the ring of standard width was variable. The mean of two upper and two lower limits for a single *S* was also 15 degrees. A number of other observers were satisfied with that equation.

The width of the narrow ring was further reduced so that it amounted to only $\frac{1}{16}$ of the diameter of the disk. The same constant intensities as in the last experiment were used. The averages of two upper and two lower limits for each of two *S*s were 37 and 37 degrees. This result means that a disk of 15 degrees intensity inside the very narrow ring looked as light as a disk of 37 degrees intensity inside a a ring of standard width. The outcome of this experiment was so striking that we repeated it with another combination of intensities. The intensity of the two rings remained the same, but the disk in the very narrow ring had an intensity of 60 degrees. Again a higher intensity was needed for an equation in the disk inside the standard ring. The averages of two upper and two lower limits for the same two *S*s were 87 and 86 degrees. However, with this intensity ratio of 120:60, which produces a light gray, the effect of making the ring very narrow was not so great. It amounted only to 45 percent, whereas in the case of a ratio of 120:15 which normally produces a very dark gray the disk in the standard ring had to be made 145 percent more intense. On the whole it looks as if the very narrow ring which has only one-quarter of the area of the disk cannot make the disk color as dark as does a ring of sufficient width.

As just reported, no difference in the effect of a ring which has about the same area as the disk and of one which has four times the area of the disk has been found. Two further measurements were made with a much wider ring. Its width was 1.5 the diameter of the disk and its area 15 times that of the disk. In one experiment the intensity ratio between the wide ring and its disk was again 120:15.

In the disk of the standard pair the averages of four upper and four lower limits for the two *Ss* were 17 and 16 degrees. When a ratio of 120:60 was used, averages for two pairs of limits were 66 and 63 degrees. The deviations from 15 and 60 degrees respectively are probably incidental. At any rate, they are not in the direction which would indicate an enhancement in the effectiveness of the ring with increased width. It seems that, once the ring has an area equal to that of the disk, any further increase in its width does not affect the resulting color of the disk.

It was reported in Part I that a ring looks more luminous than a disk of the same intensity in another pair in which the intensities of ring and disk are the same as in the first pair but interchanged. The question arises whether such a reversal of intensities also causes a color difference in the regions of equal intensity. Two pairs of disk and ring in which the area of the ring was the same as that of the disk were presented and the lights were so arranged that in one pair the lower intensity was in the ring and in the other pair in the disk. The two higher intensities in the two pairs amounted both to 360 degrees, the ring of lower intensity was kept at 45 degrees, and the disk of lower intensity was variable. Measurements were made with four *Ss*. The means of three upper and three lower limits were 54, 71, 83, 86 degrees. These figures indicate that for the same intensity ratio the lower intensity appears as a lighter gray when it is given in the ring than when it is given in the disk. A rather dark gray results from a ratio of 360:45 degrees. In the case of smaller ratios which give rise to lighter grays the differences in color which result when the intensities of ring and disk are interchanged are very much smaller. For an intensity ratio of 2:1 only a difference in luminosity can be discerned.

Summary

It was found that opaque achromatic surface colors are perceived when light of different intensity stimulates adjacent areas on the retina. The achromatic color which is seen in a particular region must be regarded as the result of stimulation received from that region *and* of stimulation from neighboring regions. Although these colors are qualities which are perceived in a given region, they are products of an interaction process, which depends on difference in stimulation in at least two areas. In the absence of a suitable difference in stimulation a color of an entirely different mode of appearance is seen. A single bright region in an otherwise dark field, for instance, looks luminous instead of white, and reducing the light intensity in that region fails to make it look gray; it continues to appear luminous and merely becomes dimmer.

The first steps were taken to investigate quantitatively the rules of this dependence in the simplest case, that of two regions of different intensities of stimulation where one region surrounds the other. The colors which come about under these circumstances depend in close approximation on the *ratios* of the intensities involved and seem independent of the absolute intensity of local stimulation. The region of higher intensity will assume the color white and that of lower intensity will show a gray (or a black) which depends on the intensity ratio of the two regions. The greater the difference in intensity the darker will be the gray which appears in the region of the lower intensity.

It can be shown that a dependence of perceived colors on the ratios of stimulus intensities accounts for the constancy of achromatic colors under varying illumination. Complete constancy would follow from this rule of interaction of two intensities. The fact that measurements of brightness constancy rarely give results which denote complete constancy presents no difficulty for this explanation. These experiments involve interaction between more than two regions of different stimulus intensity.

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STUDIES IN SPACE ORIENTATION: I. PERCEPTION OF THE UPRIGHT WITH DISPLACED VISUAL FIELDS

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I. Introduction

The experiments to be reported in the present series of papers are concerned primarily with the process of orientation toward the upright in space.

Our experienced space has the vertical and horizontal directions prominently represented within it. All objects in our surroundings are perceived as having a definite orientation: they are upright, or tilted in varying degree, or horizontal. Further, the perceived direction of an object is usually strongly indicated, and cannot be changed at will. Indeed, in a given field, the direction of an object remains constant when head or body is tilted, and seems generally independent of body position. Perception of the upright is an important function in man; we depend upon it continuously in our practical relations with objects and in our body movements. It is also an extremely broad function, involving the interaction and cooperation of visual, kinesthetic, and labyrinthine experiences.

That orientation has not been explored more intensively despite its fundamental importance seems due to a highly significant characteristic of orientation itself: the perception of the vertical and horizontal is achieved so effortlessly that it fails to become conspicuous. Under ordinary circumstances everyone is able to establish the vertical and the horizontal correctly, quickly and without deliberation. The conditions of orientation are so highly constant that disturbances are hardly ever encountered. They do, however, occur under more unstable conditions, of which the airplane is a notable example. In the plane, disorientation may be so severe that the person can be upside down and perceive himself and the plane as upright, or suddenly see the sky where he believes the earth should be, and so on. Disturbances such as these lead to an appreciation of the marked stability and orderliness which normally characterize our orientation

in space, and at the same time point up the need for a closer understanding of this function.

Aside from throwing light on a central psychological function, a study of orientation should contribute toward the clarification of several significant theoretical issues. Because the visual field is involved in orientation in a comprehensive and direct way, it should provide further evidence concerning the role of field factors in perception. More specifically, since orientation involves the employment of a frame of reference in a literal sense, its investigation furnishes an excellent opportunity to establish the role of varied and changing frames of reference. In view of the increasingly significant role of the 'frame of reference' as a systematic concept in the most diverse regions of psychology, a further investigation of it in an area where it is perhaps most simply represented should prove fruitful.

Orientation also provides an important instance of perceptual constancy. When, for example, the head is tilted or the person is inclined to one side, a correct perception of the upright is retained. Under these conditions the specific visual stimulation, represented by the angle at which the projected main lines of the field intersect the retinal coordinates, as well as bodily sensations, is markedly changed. This stability in the experience of the upright, despite marked changes in proximal stimulation, indicates the presence of a constancy phenomenon analogous to that found in the perception of size, shape, color, and brightness.

Of unusual interest in the study of orientation is the fact that it involves the manner in which the person relates *himself* to the world about him. As he perceives the position and direction of other objects, so does each person also perceive his own position and direction. To what extent is the body localized as other objects are and to what extent does its special relation to the *S* play a role? The exploration of this question may cast light on the relation of perceptual functions to features of personality organization. It would appear promising to seek for such relations first in functions as central and comprehensive as orientation.

The investigations to be reported in this series are concerned with the following questions: How do visual and postural experiences cooperate in orientation, and what are their respective contributions? How do changes in the frame of reference affect the perception of the main directions of space? What conditions are responsible for constancy of the perceived upright, and under what conditions does constancy fail? Are there individual differences in the adequacy of orientation and in mode of orientation? If such differences are present, how consistent are they, and what is their origin? Do they relate to the individual's characteristic way of coping with his sur-

roundings, even possibly in their social aspects? How can the adequacy of orientation be improved?

The first task set for investigation was that of establishing the role and relative importance of the principal sources of orientation, namely, the visual and postural experiences, and of determining the manner in which they interact in perception of the vertical and horizontal. It is therefore necessary to preface our investigations with a brief account of what is at present known about the sensory basis of orientation.

Orientation depends on two major sources of experience, the visual and postural. Through vision we perceive a space which is clearly articulated and which is organized into a framework-like structure, the main axes of which are the horizontal and vertical directions. In addition to this visual basis, there is a fund of information proceeding from the experience of our own bodies. The latter data, which arise in the course of bodily adjustment to the downward pull of gravity, include kinesthetic sensations from muscles, tendons, joints, and viscera, as well as excitations from the labyrinth.

Yet, while orientation depends on these distinct sources of information, we do not have in our experience distinct conceptions of the upright, one visual and the other postural. Our experience of spatial orientation is unitary. The final processes to which both visual and postural factors contribute produce the experience of a single upright. Indeed, there is ordinarily a close coincidence between the two systems: visually upright objects are also gravitationally upright.

This intimate and orderly relation between visual and postural factors creates a difficulty when the object is to establish their respective roles in orientation; for whether a given judgment of the upright is based on visual data or on the felt position of the body, the result is exactly the same. The role of the two systems can be studied only by means of techniques which permit their separation, and variations in the relation between them. By tilting the visual field while the body remains upright, visual and postural factors may be separated. Further, by excluding the visual field it becomes possible to observe the characteristics of orientation when based on postural factors alone. Such procedures have been used in prior studies and will also be the basis of the investigations to be reported.

The role of visual and postural factors in orientation has been the object of investigation and of systematic theory. Koffka (2) has presented the view that the main directions of visual space constitute the perceived vertical and horizontal. The visual field, according to Koffka, creates its own framework; the main lines within it assume the function of vertical and horizontal. It would follow that if our visual surroundings were to be tilted, our perceived vertical and horizontal would shift toward the new main directions. We would then perceive the new framework as upright, and the orientation of all objects within it would be perceived in relation to it.

In formulating this view Koffka based himself on the classical mirror experiment of Wertheimer (3, p. 257 ff.). In that experiment the subject

looked through a tube into a tilted mirror which displaced the image of a room by 45°. By this procedure the visual coordinates were separated from the postural coordinates and displaced by a definite amount. It therefore became possible to determine whether a given judgment of the upright was made in terms of the visual framework, or with reference to the body position, or by a compromise between the two. Wertheimer found that upon first looking into the tilted mirror the *S*s perceived the scene as tilted. A bouncing ball was seen to fall at an angle, a person walking across the room appeared to be falling to one side, and so on. However, with continued inspection, the mirror scene came gradually to look upright, and everything within it acquired a normal aspect. The interval required for the righting of the scene was believed to be consumed in a gradual 'wearing off' of the framework of the outer world.[1] This acceptance of the new framework Wertheimer interpreted as evidence of the importance of visual field-factors as against postural factors.

A fundamentally different emphasis concerning the basis of orientation is found in the work of Gibson and Mowrer (1). While these writers acknowledge the importance of visual factors and their effect upon postural data, they believe that our orientation in space is anchored mainly to postural factors. The latter are decisive in situations of conflict and are genetically primary. Visual stimulation, they assert, cannot be a basis for orientation unless postural orientation is already presupposed. Indeed, they go as far as to claim that the primacy of postural factors is a logical requirement, that the visual framework develops in the context of maintaining the postural equilibrium in response to the pull of gravity.

We cannot here consider the full basis of evidence for the formulation of Gibson and Mowrer. Of more immediate relevance are the observations made by Gibson when he repeated the mirror experiment of Wertheimer with results that he claimed to be different. Gibson's *S*s looked through a tube into a tilted mirror, the images of which were displaced approximately 30°. They perceived the tilt from the start and also reported a lessening of the tilt with continued observation. However, the scene did not fully right itself. Only with a special effort could the *S*s momentarily feel themselves into the room. Generally, however, they did not feel themselves part of the tilted room, the position of the body remaining "an omnipresent factor in the seeing of the room." [2] In opposition to Wertheimer, Gibson concluded from these observations that judgment of the upright is anchored mainly to the body.

It is clear that in order to establish the respective roles of the visual and postural systems in orientation it is necessary to clarify the apparent contradiction between the reports of Wertheimer and Gibson. This was attempted in the present study, where the mirror experiment was repeated with a large number of *S*s and under several different conditions.

[1] Wertheimer also tested the ability of the *S* to set a white line on a black ground to the vertical before and after the observation of the mirror scene. He reported that after the tilted mirror scene had become upright the setting of the vertical became uncertain and variable.

[2] Gibson and Mowrer report results essentially similar when *S*s viewed the surroundings through prisms tilting the field from between 10° and 45°.

II. The Experiment

The top of a 48 by 40 in. mirror was tilted back by 15° from the vertical. The scene which it provided had, therefore, a tilt of 30°, or twice that of the mirror. The result was equivalent to placing the *S* in front of a visual field tilted backward by 30°. The *S* was brought into the laboratory blindfolded, and placed in a standing position in front of, and slightly to one side of the mirror. A circular cardboard tube, two feet long and nine in. in diameter, through which he was to view the mirror scene, was placed over his face. This tube was tilted downward by approximately 30°, in order to include a view of the floor of the scene, and the farther end of the tube was eight in. from the mirror surface. The *S* remained blindfolded for a period of three minutes. Before the blindfold was removed, the *E* read the following instructions: "When you open your eyes, you will be observing a scene. Try to describe what you see of the room and the objects in it." *S* was not informed that he was facing a mirror and he was not questioned at all about the tilt of the scene until the observation period was over. Upon opening his eyes *S* saw the reflection of a portion of a large laboratory, including tables, chairs and apparatus. A great part of one wall and of the floor of the room, and of the scene outside one of the windows, were also visible. The view excluded the reflection of *S*, the tube and the mirror edge.

After he had described the scene for a period of two min., *S*'s perceived vertical was measured. For this purpose, a rod 2½ ft. long and pivoted at its center was used. The stand on which the rod was mounted was placed on a table which was parallel to the visible wall of the scene. The rod was capable of rotation in a plane parallel to this wall—that is, toward *S* or away from him. The rod stood 12 feet to the back and 15 feet to the left of *S* so that in the mirror it appeared to be in front and to the left of him. Since the plane in which the rod moved was to the left, it was slightly oblique to *S*. There was no difficulty, however, in seeing the plane clearly. A square cardboard mounted on the side of the table toward *S* excluded from view the stand and a protractor fixed to the stand in back of the rod. Before the measurements were taken the *E* read the following instructions: "You see the rod on the small table. The experimenter is going to move the rod gradually. We want you to tell us when the rod is perfectly upright, that is, when it is parallel to your body. As the experimenter moves the rod, you will say 'now' when it reaches this position. We will take a few measurements."

During the observation period the rod had remained perpendicular to the floor. It was now moved to a near-horizontal position. The *E* then moved it slowly in steps of two degrees until *S* indicated that it had reached the vertical. Four successive measurements of the vertical were taken with the rod returned to a near-horizontal position on each trial. On the first and third trials the rod was moved in a counter-clockwise direction from its initial position; on the second and fourth it was moved clockwise.

When the measurements had been taken *S* was told to close his eyes and led to an adjoining room. He was then questioned in detail regarding his observation of the tilt. After this he was returned to the experimental room with eyes open and placed directly in front of the tilted mirror *without* the tube. It will be noted that *S* was now much nearer to the mirror than in the first test with the tube. From this position *S* saw the reflection of the room in the mirror, but he also saw the mirror, its edges, and his own reflection. He was specifically cautioned to align the rod-image with his body and not with the image of his body. Four measurements were taken in the manner described above.

It will be noted that both with and without the tube the instructions explicitly directed *S* to align the rod with the felt position of his body. This was done to insure maximum attention to the body as a basis for judgment. Also, to fail to instruct *S* in this way would have left the task ambiguous.

A word of explanation should be given concerning the readings obtained with the rod. If the *S* accepts the tilted mirror scene as upright, in making the rod image upright he will adjust it to the axes of the scene. The rod image will therefore deviate from his body position by 30° or to the extent of the tilt of the scene. At the moment, of course, the rod is objectively upright, and the reading on the protractor is therefore zero degrees. The position of the *S*'s perceived vertical, which is 30° off the true vertical, is found by subtracting zero degrees from 30°. At the other extreme, if *S* takes full and proper account of the tilt of the scene, he will bring the rod image to the true upright. The rod image will therefore deviate from his body position by zero degrees, or will be at a 30° angle with the vertical axis of the scene. In this case, the rod itself

is objectively tilted by 30°, so that the protractor reading will be 30°. To obtain the position of the *S*'s perceived vertical, which is at zero degrees, it is necessary to subtract this value from 30°.

In brief, by subtracting the protractor reading from 30°, the position of the perceived upright may be determined. In cases where the protractor reading is negative, indicating that the rod image has been displaced even farther than the tilted scene, a value of 30° is added to the reading. In any case, the larger the value obtained, the farther has the perceived upright been shifted, under the influence of the tilted visual field. All results will be given in terms of the deviation of the rod image from the true upright, or from the position of the body.

49 *S*s, all college students, were used in this experiment.[3]

III. Results

Figs. 1 and 2 present for the with-tube and without-tube conditions respectively, the distribution of the deviations of *S*'s perceived

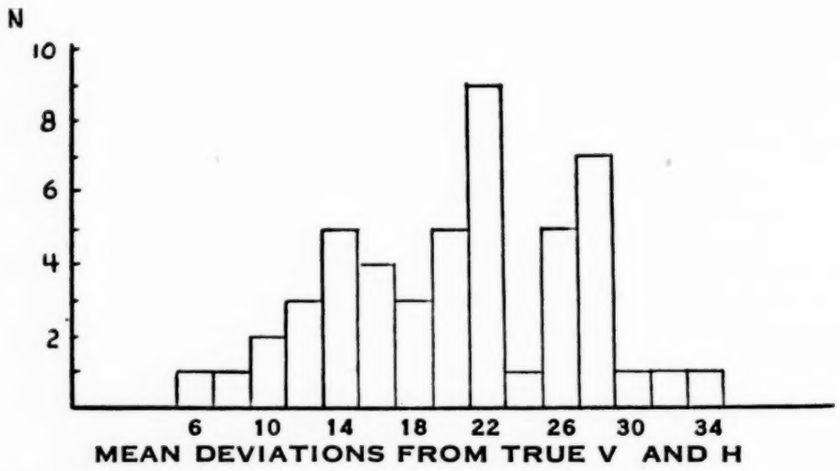

Fig. 1. Distribution of individual scores when the rod was adjusted with the tube. *N* is 49.

vertical from the upright position of his body. The score of each *S* is based on four measurements.

The following are the principal results of the experiment:

1. When *S*s viewed the mirror scene through the tube, the perceived upright deviated toward the axes of the tilted mirror world to a remarkable degree. The average setting of the rod for the group of 49 *S*s was 21.5° from the true vertical. In short, the perceived vertical was very much nearer to the mirror axes than to the position of the body. An appreciable number of *S*s accepted the tilted scene either as completely upright or as almost completely upright.[4]

2. Even more striking are the results obtained when the *S*s stood directly in front of the mirror and looked at the tilted scene without

[3] The writers wish to express their appreciation to Mr. Richard Hoffman for his assistance in the present experiment.

[4] Whenever an *S* started by aligning the rod with the tilted scene he was reminded that he was to take the position of his body as the reference. Some *S*s 'forgot' this part of the instructions, though it was read to them with emphasis. In some cases, following the reminder the *S* did refer to his body with some measure of success.

a tube. Although the *Ss* now knew that they were looking at a mirror (something of which most *Ss* were unaware when looking through the tube), they localized the vertical far nearer to the axes of the tilted scene than with the tube. Now the average deviation of the perceived vertical from the true upright was 26.4°, or less than four degrees from the main axis of the mirror world.

3. Under both conditions of observation the range of individual differences is great, extending over nearly the entire region between the true upright and the 30° tilt of the mirror scene. In a few cases, in fact, scores greater than 30° were obtained. (See Figs. 1 and 2.) When looking through the tube, one *S* at one extreme compensated

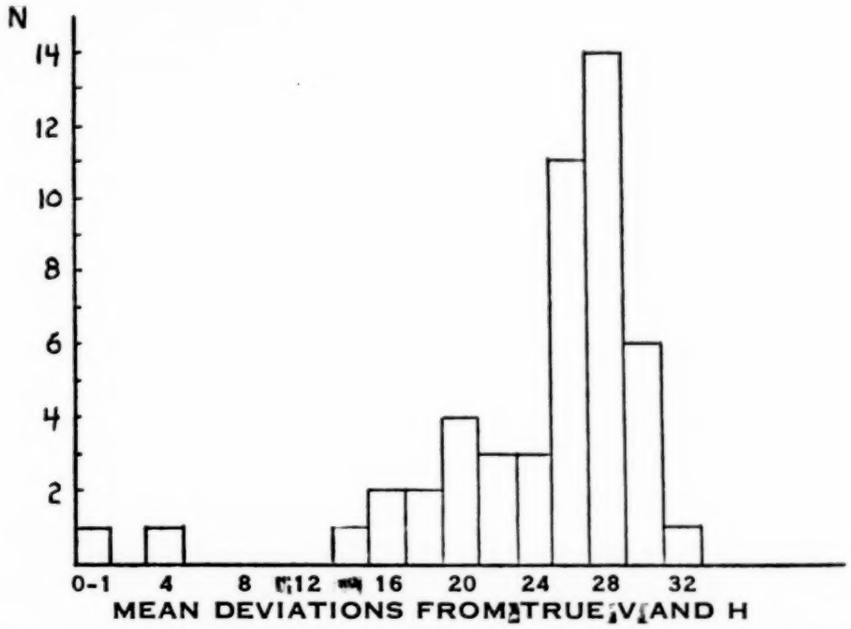

FIG. 2. Distribution of individual scores when the rod was adjusted without the tube. *N* is 49.

for the tilt of the visual surroundings to an extent where he succeeded in bringing the rod to within an average of six degrees of the true upright. On the other hand, 15 out of the total of 49 *Ss* gave deviations of 26° or more. Without the tube, though there is a greater concentration of cases toward the upper end of the distribution, the range of individual differences persists. At the one extreme is an *S* who compensated completely for the tilt of the scene so that his deviation was zero degrees; while 32 *Ss* at the other extreme gave deviations of 28° or higher.

In the course of the experiment a number of qualitatively different reactions were obtained which will now be described.

Six *Ss* reported that the scene which they saw through the tube was perfectly upright. Two of these continued to perceive the mirror

room as upright when they viewed it *without the tube.* This group of six was clear in asserting that the scene appeared upright throughout the period of observation, and were amazed when they subsequently saw the mirror. In the case of one *S* the mirror was turned to the upright while his eyes were closed. When asked subsequently to report what changes he observed he replied: "New objects have come into view," but he insisted that the scene was as level earlier as it was now.

In general, these *S*s expressed deep surprise when they saw the mirror upon removing the tube from the face. One subject reported: "I am astounded. I didn't think it was possible to make such a mistake." Another asserted: "I was completely absorbed in the picture. It seems hard to believe that the room was tilted, everything appeared perfectly straight." Another *S* reported: "No, this is not what I saw before. The whole thing is slanted now. It seems to have shifted. I didn't know I was looking into a mirror." One of the *S*s, when returned to the scene said: "The scene looked perfectly straight before. The floor looked level, I felt I was looking at an extension of the room." The mean deviation of the perceived upright from the true upright for this group of six *S*s was, with the tube, 28.5°. The 1.5° displacement from the tilt of the mirror scene was probably within the experimental error of measurement. Without the tube, five of these *S*s set the vertical at 29.5° from the true upright, or within half a degree of the vertical of the mirror scene.

The greater number of the 49 *S*s, 43, perceived the scene as tilted when viewed through the tube. (The frequency with which the tilt was perceived was very likely increased by the initial instructions, which specifically directed *S* to align the image of the rod with the felt position of the body.) The reports of these *S*s, however, reflect considerable differences in emphasis, which may be important for subsequent investigation.

First, six of these *S*s perceived the scene as tilted when viewed through the tube, but attributed it to their own position. In the words of one *S*: "I seemed to be at an angle: *I* was the one off." It is of particular interest that this *S*, whose vertical deviated from the true value by 19°, felt that the real vertical was that of the visual field, and that in taking his body position into account he was departing from the true value. An almost identical statement was obtained from another *S*: "The room looked all right to me; it seemed as if I were standing at an angle. The true upright was that of the room." Another *S* reported: "I had the optical impression that I was at an angle myself." Still another *S* said: "I feel I am leaning backward." The following report is also of interest: "The room had a queer appearance, its perspective was strange but I was not aware

except at moments that it was tilted. Sometimes it was as if I were looking at the scene from a somewhat peculiar point of vantage."

The remaining 37 *Ss* in this group of 43 who reported the room to be tilted, spoke of the room as actually appearing tilted. This they often ascribed to the position from which they observed the scene rather than to the scene itself. In their comments some tended to speak of the tilt in terms of the relation between their position and that of the room, rather than in terms of a tilt either in the visual surroundings or in their body position.

Those *Ss* who perceived the tilted scene as upright placed the vertical, as described above, in alignment with the vertical axes of the mirror-room. Equally extreme results were also obtained with *Ss* who did perceive the tilt. This was most notably the case when *S* stood directly in front of the mirror without the tube. Under these conditions 19 *Ss* gave deviations which were within two degrees of the tilt of the scene. Of these, two saw the scene as upright. The remaining 17 *Ss* saw the scene as tilted, but despite this, adjusted the vertical essentially to the mirror-room axis. These latter *Ss* were aware, or they were made aware, that since the surroundings were tilted and their position upright, the rod as they placed it could not be parallel with the upright body. Despite this knowledge, they could not find another position in the mirror-scene that fulfilled this requirement. One *S* fully conversant with the problem reported: "I see the room as tilted, and the rod as vertical (at a deviation of 30°), even though the table nearby appears tilted. Any position of the rod away from this appears as distinctly tilted. This is the only possible vertical in the scene." Another *S* commented: "This is virtually impossible. . . . I will say it is vertical now (at a deviation of 30°) but I don't think I'll ever get it right. It will never achieve the position at which I am standing." Another *S* reported: "I can't tell when I think the rod is vertical in relation to my body because I'm always relating it to the walls."

There were a few *Ss* who in an attempt to take the body into account, tilted the rod further than the scene itself. One *S* tilted the rod once 40° from the position of his body, another 35°. When these *Ss* attempted to relate the position of the body to the visual vertical they became entirely confused and the error in judgment of the upright became greater than it would have been if the body position had been completely neglected.

Of particular interest is the difference in results obtained with the tube and without it. It would have been plausible to predict that the visual vertical would be less affected by the tilted scene when *S* had full knowledge that a mirror was being used and was actually able to see the tilt of the mirror. Yet the opposite was the case. In 31

out of 49 cases the deviations in the direction of the tilted scene increased when the tube was eliminated. (Only differences greater than two degrees were considered significant.) Further, the increases in the deviation of the vertical were often large, reaching, in one case, 21.5°. In contrast, there were only five *Ss* whose deviations were greater without the tube than with it. Often, after having adjusted the rod without the tube, *S* would change it, in the direction of smaller deviations from the true upright, when the tube was restored.

The greater effect of the tilted visual scene when the *S* looked into the mirror without the tube seems to be due primarily to the more lifelike quality of the scene under the latter conditions. The *S* now perceived a far wider expanse in contrast with the previously more restricted and somewhat more artificial view. Also, the scene was far richer in objects and details and, though extending only to the space in front of him, it seemed also to surround him. Despite his more accurate knowledge of the true conditions, *S* found it far more difficult to isolate a single line from the surroundings and to relate it to his body position.

The reports also indicate that the tube helped many *Ss* considerably in determining the vertical. Often *S* would take note of how the image of the rod cut the circular opening of the tube. At other times *S* would relate the rod to the position of his face, or more particularly, to the line joining the eyes. In effect, the vertical was in these cases established by a process of isolation. The image of the rod was divorced from the surroundings of the room and its position estimated with reference to the face and tube. While in using this approach the *Ss* were not always wholly successful, many were able to reduce the extent of the deviations considerably. At the same time there were considerable individual differences in this regard. There were *Ss* who could not separate themselves from the visual scene, and indeed became confused when they attempted to relate the vertical to the position of the body.

Though the problem of the righting of the tilted scene was not studied systematically, three *Ss* who in the with-tube condition, initially perceived the scene as tilted reported after continued observation that it became less tilted, or that the tilt disappeared completely. One *S* whose initial deviation (based on 4 determinations) was 8.5° from the true upright or 21.5° from the mirror, came to see the room as perfectly upright. A new set of four measurements was taken, yielding an average deviation of 28.2° from the upright or 1.8° from the mirror. In the words of one *S*: "At the beginning it (the floor) was at an angle. Then it straightened itself. Later it (the tilt) completely disappeared." Another *S* reported: "It is beginning to look as if it were level. Now I see the room as perfectly straight."

IV. Discussion

The present experiment has provided striking evidence of the predominance of the visual framework over postural factors in perception of the upright. Since the body remained erect while the visual field was displaced, the visual and postural systems were brought into conflict. It was found with this technique that the perceived upright was always much closer to the visual than to the postural vertical. In the first experimental condition, where the tube was used, the perceived upright was displaced by an average of 21.5° from the true upright—that is, from the position of the body—or by only 8.5° from the upright of the mirror scene. In the second condition, where the tube was removed and the *S* brought closer to the mirror, the results were even more striking, with the perceived upright now deviating by an average of 26.4° from the true upright, or by only 3.6° from the upright of the mirror. Under each condition, not only did nearly all *S*s perceive the upright primarily in terms of the coordinates of the visual field, but an appreciable number adopted these coordinates completely. These results were obtained though the *S*s were emphatically directed to take the postural system as their standard. It is also to be noted that the technique employed gave full play to the gravitational factors. The *S* was outside the tilted field; moreover, because he stood erect he had the optimum opportunity to determine the position of his body accurately, and to involve his body in judging the upright.

Equally important is the finding of large individual differences. Both with the tube and without it, the range of the *S*s' determination of the upright was great, covering the greater part of the region between the true upright and the upright of the tilted visual field (see Figs. 1 and 2). Under each condition, many *S*s were markedly affected by the visual field; their body position seemed virtually without effect. Indeed, some *S*s became confused and their errors increased when they attempted deliberately to refer to their bodies. At the other extreme there was a much smaller number of *S*s who perceived the vertical primarily with reference to the position of the body.

The results indicate that perception of the upright is also clearly affected by the specific structure of the visual field. When the view was more articulated and life-like, as was the case when the *S*s looked into the mirror without the tube, the effect of the visual coordinates was markedly strengthened. This observation is particularly significant since the changed structure of the visual field acts on a strictly perceptual rather than on a cognitive basis. Though without the tube the *S* had full knowledge of the tilt of the field, and of the extent of the tilt, this knowledge proved ineffective in the perception of the vertical. Indeed, despite the knowledge, the visual field exerted a

greater influence upon perception than when this knowledge was not available, as was the case when the tube was used. It is indicated that under the given field-conditions the *S* perceives the upright in a determined way; he cannot alter its direction, not even when he possesses the knowledge that would suffice to provide the necessary correction.

The present findings, based on a more intensive study and on a larger number of *S*s, help to settle the apparent contradiction between the observations of Wertheimer and Gibson. Contrary to Gibson's conclusion that under conditions of conflict between visual and postural factors the shift of the perceived vertical toward the visual coordinates is slight, in the present experiment most individuals showed a very marked shift in the perceived vertical. Also, the conclusion of Gibson that the visual field does not right itself under the given conditions is not in full accord with the results obtained here. While the effect of prolonged observation of tilted visual fields was not investigated systematically in the present experiment, a substantial number of *S*s accepted the tilted visual framework as upright from the very outset, indicating that full righting of the field may even occur at once, without the need for prolonged observation. The results of the present study demonstrate that the visual framework plays a much more decisive role in establishing the upright than postulated by Gibson. In this regard they tend to support the conclusions reached by Wertheimer. It is indicated by some of our findings that a possible reason for the difference between Gibson's and our own results may lie in the smaller number of cases employed in Gibson's study. It has been established here, by using a large group of *S*s and testing them with a quantitative technique, that there are important individual differences in the mode of perceiving the upright. Consequently, if a small group of *S*s is employed in a given condition, the results obtained may not represent the general situation. It is accordingly possible that because he used a small group, Gibson may have been tapping one segment of the population. Because Wertheimer also used a small number of *S*s in his study, it is possible that selective factors in the group used may similarly account for the difference in observations between Wertheimer and Gibson.

For the reasons mentioned the more general assumptions of Gibson and Mowrer concerning the genetic and indeed the logical primacy of postural factors will require reexamination. Such a comprehensive evaluation must be reserved until the results of further investigations have been reported.

V. Summary

In this first of a series of studies on space orientation, an effort was made to determine the relative importance of visual and postural

factors in perception of the upright. Since these two systems normally function together, it was necessary to separate them in order to establish the specific contributions of each. For this purpose, the mirror technique, employed by Wertheimer in some of his investigations, was used. By requiring the *S* to look into a tilted mirror scene while his body remains erect, we have essentially a situation where the visual coordinates are displaced while the postural upright remains unchanged. With this technique it was possible to determine whether the perceived upright is based mainly on the axes of the visual field or on the position of the body. In an experiment with 49 *S*s striking evidence was found of the primary importance of visual factors in perception of the upright, and of the secondary role of postural determinants. Though most *S*s were greatly influenced by the titled visual field in making their judgments, there were found significant individual differences in this regard. Some *S*s accepted the tilted field entirely, perceiving it as fully erect, while others, at the opposite extreme, were able to make full allowance for the tilt of the scene, and in their judgments succeeded in approximating the true upright. Experiments in which the tilted scene was viewed with a tube and without a tube have domonstrated that the specific structure of the visual field affects the manner of perceiving the upright in a specific way. Some of the differences in conclusions between Wertheimer and Gibson, derived from this same mirror technique, are considered in light of the results of the present experiment.

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References

1. Gibson, J. J., & Mowrer, O. H. Determinants of the perceived vertical and horizontal. *Psychol. Rev.*, 1938, **45**, 300–323.
2. Koffka, K. *Gestalt psychology*. New York: Harcourt Brace, 1935.
3. Wertheimer, M. Experimentelle Studien über das Sehen von Bewegung. *Z. Psychol.*, 1912, **61**, 161–265.

THE CONDITIONING OF THE HUMAN FETUS *IN UTERO* *

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It is commonly recognized that environmental factors influence the organism from the moment of fertilization, but experimental studies of their effects on the behavior of mammalian fetuses have usually disturbed the fetal environment severely. The possibility that conditioned response technique provides a method which would eliminate resort to surgery has long been seen. Successful conditioning of young infants (**2, 3, 6, 7, 8, 10**) and of sub-human mammals in which neural structures had been damaged (**1, 11, 12, 13**) indicated that lack of cortical development in the fetus presented no problem. Ray (**15**) made the first attempt, using the previously reported fetal response to loud sound (**4, 14**) which he sought to condition to a vibrotactile stimulation applied to the maternal abdomen. Although results on his single case were inconclusive, his use of individual receiving tambours, taped to the maternal abdomen over the fetus, eliminated much distortion of records by maternal breathing. This study was suggested by Ray's work and resembles his in general procedure.

Apparatus

The source of noise (US) was a box 29¾ in. square, 10⅝ in. deep, made of ½ in. pine stock. It stood on one side, surmounted by a metal framework which carried an oak clapper five in. wide, 22½ in. long, and one in. thick. Pivoted one in. from the top, the clapper had a narrow steel handle nine in. long. A steel spring ran from each edge of this handle to the supporting framework, so that a pull of some eight pounds was necessary to raise the clapper, through an arc of 85°, to the stop which limited its excursion. When released the clapper struck the face of the box sharply, closing a circuit through a dry cell and signal marker. On top of the box were mounted all the controls for *E*'s use.

Vibrotactile stimulation (CS) was provided by an ordinary doorbell, with the gong removed, the striker bent outward at an angle of 90° to its original position, and the interrupter soldered shut. The striker vibrated strongly but almost silently in response to four volts of 60-cycle A.C. This stimulator, fastened to a block of wood, was held in an adjustable metal clamp at the end of a movable support affixed to the side of the bed in which the *S*s lay. Thus, the striker could be made to vibrate perpendicularly to the surface of any part of the abdomen. A dual key controlled the transformer-stimulator circuit and a dry cell-signal marker circuit.

* This study was conducted, under the direction of Dr. J. F. Dashiell, in partial fulfillment of the requirements for the doctoral degree at the University of North Carolina. I am indebted to The Watts Hospital, Durham, North Carolina, and to Dr. R. A. Ross, Chief of Obstetrical Department there, for generous cooperation. My greatest debt is to Elizabeth P. Spelt, who contributed to every phase of the work, including the arduous analysis of hundreds of feet of kymograph records. The costs of the research were met by a series of grants from the Smith Research Fund of the University of North Carolina Graduate School.

Fetal movements were recorded by means of three pairs of 50-mm. receiving tambours taped to the maternal abdomen, each pair connected to a one-inch recording tambour. The method of placing the tambours is described below. *S* operated a signal marker whenever she felt fetal movement by pressing a push button which she held in her hand. A Manning pneumograph (**16**) connected to a one-in. recording tambour supplied records of maternal breathing. An electric clock and signal marker provided a time line marked in intervals of five sec.

All recording devices were vertically moving ink-writers which bore upon an electrically driven long-paper kymograph. The kymograph, apparatus controls, and *E* were screened from *S*'s view when she lay in bed, as indicated in Fig. 1.

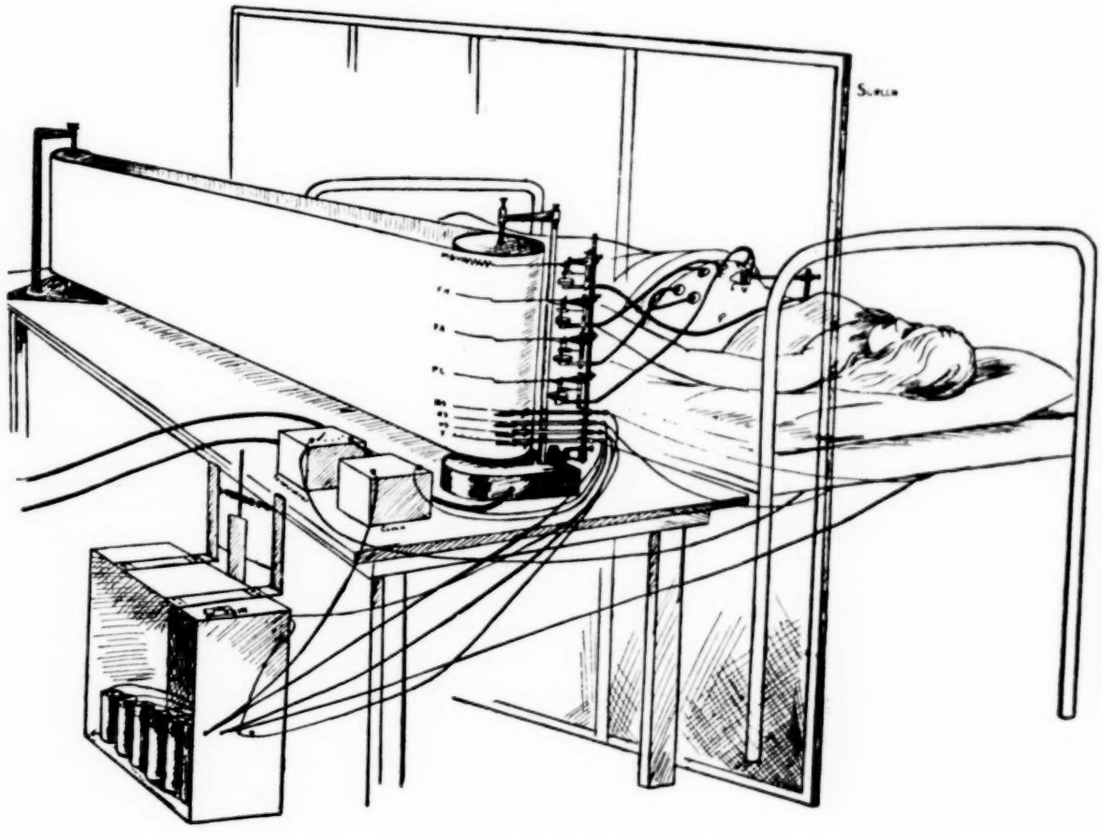

FIG. 1. Sketch of apparatus arrangement for fetal conditioning study

SUBJECTS AND PROCEDURE

Except for three non-pregnant control *S*s and one of the pregnant *S*s, all 16 *S*s were selected from patients attending the obstetrical clinic of an urban hospital. All but two were past the seventh calendar month of gestation. Only patients whose histories were free from evidence of pathology during pregnancy were considered, and only those willing to participate actually served as *S*s. Not that *S*s knew they were taking part in an experiment, for the word was scrupulously avoided by everyone who dealt with them. *S*s were told that since confinement was approaching and since their progress thus far had been excellent, the staff wanted some 'special information' to be obtained from X-ray pictures and from records of fetal movements to be made twice daily for 10 days or two weeks. They were told that no cost was involved, and that they would be guaranteed free care in the hospital's obstetrical ward when they came to term. Since the hospital was sufficiently crowded to admit only a fraction of the group attending the clinic, certainty of admission was an important reward. It was made quite clear, however, that they were free to decline without jeopardizing the normal chance of admission, for no record was made of their decision on the clinic card. A few of those interviewed did so decline.

After appointments for subsequent admission to the hospital had been arranged, each *S* went to the radiological department, where two X-ray pictures of the abdomen were made: an

anteroposterior view and a lateral view. These plates and the radiologist's report were available well in advance of the admission time for each *S*.

Each pregnant *S* entered the obstetrical ward on the day of her appointment as a regular patient, and was required to rest in bed for at least a half-day before the first experimental period. When she went to the experimental room for the first time, the operation of the instruments was superficially explained, but no insight into the problem was provided, nor did any *S* ever have an opportunity to examine the records until after her last session. Even then no information beyond the original statements made in the first interview was offered, lest the study become a matter of ward gossip.

Before each experimental period the assisting nurse applied the pneumograph to *S*'s chest and put her to bed. In an effort to record fetal movements as adequately as possible, the data from X-rays, external manual examination, and fetal heart sounds were employed to determine the position of the fetus. One pair of receiving tambours was taped to the abdomen over the fetal head, another over the fetal arms, and the third over fetal legs.[1] It was never supposed, however, that selective records were thus obtained, or that movements recorded from one area had different significance from movements recorded elsewhere. Next, the vibrotactile stimulator was adjusted at some convenient spot on the abdomen, although its location varied for every *S* from time to time. Then *S* took the push button with which she indicated that she felt fetal movement. Finally, *E* connected the abdominal tambours and the pneumograph to the recording apparatus, and started the clock and kymograph.

Procedure during the first experimental periods varied slightly for different *S*s. Most *S*s had two sessions daily, lasting from 30 to 75 min. each, depending largely on *S*'s comfort. Three *S*s in the experimental group (Group I, nos. 10, 12, 15) received 8–16 successive US, followed by 3–10 successive unreinforced CS (five sec. each) as a control for the possibility of pseudo-conditioning. The other *S*s in Group I (nos. 16, 17) received 5–15 successive unreinforced CS without prior US. Actually, only three CS were needed to demonstrate the indifference of the vibrotactile stimulus, since it never elicited a response, without reinforcement, after three successive failures. *S*s were warned about the noise on the first trial or two, but very few were startled, even on the first day.

Conditioning procedure involved presentation of CS for five sec., terminated by the loud noise (US). Since Ray had shown that successful stimulation of the fetus induces a 'refractory period' lasting some four min., the principle of separating successive stimulations by intervals of somewhat greater length was followed, except on one or two occasions when the validity of the principle was checked.

Special control groups were treated somewhat differently. Thus, Group II consisted of six *S*s (nos. 1, 3, 4, 8, 9, 14) with whom the CS alone was tested for indifference during the last two months of pregnancy. Group III included three non-pregnant *S*s (nos. 19, 20, 21) each of whom served for two 'conditioning' periods. In Group IV were two *S*s (nos. 5, 18) with whom the effect of fetal age on the response to sound (US) alone was investigated by beginning presentation in the seventh month of gestation.

Results

Group I.—Two *S*s in this group had displayed indications that the conditioning procedure had been effective, when the experiment was interrupted by labor. S-10 during the first four sessions received 16 successive US followed by 10 successive CS. Although the fetus responded regularly to the noise, the vibrotactile stimulus was ineffective. By the eighth session three successive responses to CS alone appeared, but labor began the following day. Similarly, with S-17 three successive responses to CS alone appeared by the eighth session, but the onset of labor precluded further experimenting.

[1] In 12 of 13 cases the fetus was in cephalic presentation at the time of X-ray; in 10 of 13 cases, the fetal back was to the left, with the head usually in the left occiput anterior position.

Results with the other three *S*s in Group I will be presented in greater detail. Records of S-16 showed the first fetal response to CS alone after 21 paired stimulations, and others appeared at intervals until in the sixth session, after 59 reinforced presentations, a series of seven successive CRs occurred. At the beginning of the seventh session the next morning, and with no reinforcement, four more CRs were elicited, followed by irregularly spaced responses as experimental extinction developed. There was no indication of recovery of the response the following day, although US was still effective. These data are summarized in Table I.

TABLE I

Results from Subject 16. Trial numbers in italics indicate unreinforced presentations of the conditioned stimulus; all others are paired presentations. Letters in the Resp. column show which recording systems revealed the response: H—fetal head; A—fetal arms; L—fetal legs; M—maternal signal. This *S* had only one experimental period per day; the interval between successive days is indicated by the dashes.

Trial	Resp.	Trial	Resp.	Trial	Resp.	Trial	Resp.	Trial	Resp.
14	LM	32	HALM	50	HA M	67	H LM	*84*	
15	LM	33	HALM	-----	-----	68	H	*85*	
16	H LM	34	HALM	51	ALM	69	H M	*86*	H M
17	H LM	35	LM	52	H M	70	HALM	*87*	
18	LM	*36*	LM	53	LM	71	HALM	*88*	HALM
19	H LM	37	ALM	54	ALM	72	H	*89*	
20	ALM	-----	-----	55	HALM	*73*	HALM	*90*	
21	LM	38	H LM	56	M	*74*	ALM	*91*	H LM
22	M	39	H LM	57	LM	*75*	HALM	*92*	
23	H LM	40	H LM	58	ALM	*76*	HALM	*93*	
24	HALM	*41*	H LM	59	HALM	*77*	HALM	*94*	
-----	-----	*42*		60	ALM	*78*	HALM	*95*	
25	LM	43	ALM	*61*		*79*	HALM	-----	-----
26	A M	44	HA M	*62*	ALM	-----	-----	*96*	
27	ALM	45	H M	-----	-----	*80*	A M	*97*	
28	ALM	46	HALM	63	H M	*81*	H LM	*98*	
29	H LM	47	HALM	64	H M	*82*	HALM	99	HALM
30	HALM	*48*	A M	65	H LM	*83*	H M	*100*	
31		*49*		66	HALM				

S-15 received 10 successive US followed by three successive CS during the first two sessions. As before, the noise was effective, the vibrotactile stimulus ineffective. The first response to CS alone occurred in the sixth session after 16 paired stimulations. Others occurred irregularly, but since this *S* was still in the eighth month of gestation, she was allowed to leave the hospital at her own request after the eleventh session. She returned two weeks later and the experiment was resumed. The CS alone was ineffective, but after 31 reinforcements six successive CRs appeared, followed by experimental extinction. With 12 more reinforcements the CR was reinstated at the end of the session. The data obtained after *S*'s return are summarized in Table II.

S-12 was perhaps the most interesting of the group, because of the extensive study of the CR which was possible. During her first two sessions, eight successive US were followed by four successive CS which were ineffective. The earliest response to CS alone came in the seventh session after 21 paired stimulations, when on two successive trials (Table III, nos. 27–28) CRs occurred. Three more CRs were obtained at the beginning of the ninth (nos. 40–44). When four successive CS produced no direct record of fetal response (nos. 55–58), *S* was permitted a 24-hour rest period to see whether spontaneous recovery would develop. That such recovery occurred is evident. Eleven successive CS alone produced six clear reactions

TABLE II

Results from Subject 15. Trial numbers in italics indicate unreinforced presentations of the conditioned stimulus; all others are paired presentations. Letters in the Resp. column show which recording systems revealed the response: H—fetal head; A—fetal arms; L—fetal legs; M—maternal signal. Intervals between sessions on a single day are shown by asterisks, between sessions on successive days by dashes.

Trial	Resp.	Trial	Resp.	Trial	Resp.	Trial	Resp.	Trial	Resp.
72		86	AL	98	A	111	ALM	124	LM
73	HALM	-----	-----	99	HA	112	HALM	*****	*****
74	L	*87*		100	A	*113*	HALM	125	
75		88	HAL	101		*114*	HALM	126	L
76		89	L	102	HALM	*115*	HALM	127	L
77	ALM	90		103	HALM	*116*	HALM	128	
78		91	HA	104	L	*****	*****	129	ALM
79		92	HA M	105	HALM	*117*	AL	130	LM
******	*****	93	HALM	-----	-----	*118*	L	131	ALM
80		94	HALM	106	LM	*119*		132	ALM
81		95	HA M	107	AL	*120*		*133*	
82	ALM	******	*****	108		*121*		134	M
83	L	96	LM	109	L	122	L	*135*	
84	L	97	L	110	HA	123	HAL	*136*	LM
85	HALM								

in the fetal records and on two other trials the maternal signal was pressed (cf. Table III, trials 59–69). The response was then extinguished again, although the fetus still responded to the noise. *S* was then discharged, but returned to the hospital 18 days later as a result of false labor. Hence it was possible to resume experimental work exactly three weeks after the last previous session. In the next two periods, CS was presented alone 12 times in succession; seven of the first nine stimuli were effective, showing retention of the response over this interval, while the last three were ineffective. On the next day only two CRs were elicited in eight trials, and *S* was again discharged. She returned 13 days later, when X-rays showed that the fetus was probably past term, but it was possible to run one more experimental session before labor was medically induced. There was

no response to CS alone although the two stimuli together were effective. These data appear in Table III.

Group. II.—This group included six *S*s, all in the late eighth or the ninth month of pregnancy, with whom the CS alone was tested to discover whether it became effective simply as a result of advancing fetal maturity. Although each *S* received 4–7 unreinforced vibrotactile stimuli, none of the 32 trials elicited a response.

Group III.—In this group were three non-pregnant *S*s, members of the hospital's staff, each of whom served for two standard experi-

TABLE III

Results from Subject 12. Trial numbers in italics indicate unreinforced presentations of the conditioned stimulus alone; all others are paired presentations except no. 91, which was the sound alone. Letters in the Resp. column show which recording systems revealed the response: H—fetal head; A—fetal arms; L—fetal legs; M—maternal signal. Intervals between sessions on a single day are shown by asterisks, between intervals on successive days by dashes. Longer intervals are specifically stated.

Trial	Resp.	Trial	Resp.	Trial	Resp.	Trial	Resp.	Trial	Resp.
22	M	*41*	LM	*58*		*77*		*95*	
23	L	-----	-----	-----	-----	*78*		*96*	
24	A	*42*	LM	*59*	M	Three weeks'		97	ALM
25	LM	*43*	L	*60*	ALM	interval		98	LM
26	LM	*44*	LM	*61*		*79*		*****	*****
-----	-----	*45*		*62*	LM	*80*	AL	99	HAL
27	ALM	*46*		*63*		*81*	L	100	AL
28	A M	*47*		*64*	ALM	*82*	L	101	HAL
29	M	*48*		*65*	L	*83*		102	L
30	A M	*****	*****	*66*	M	*84*	ALM	103	
31	ALM	*49*		*67*	LM	*85*	LM	104	L
32	L	50	ALM	*****	*****	*86*	LM	*105*	
33	ALM	51	M	*68*	ALM	*87*	A	*106*	L
*****	*****	52	LM	*69*	ALM	*88*		*107*	
34	LM	53	ALM	*70*		*89*		13 days'	interval
35	LM	54	LM	*71*		*90*		*108*	
36	LM	-----	-----	*72*		91	LM	*109*	
37		*55*	M	*73*		-----	-----	*110*	
38	L	*56*		*74*		*92*		*111*	
39	LM	*57*		*75*	ALM	*93*	LM	112	HALM
40	ALM			76	LM	*94*		113	AL

mental periods. Presentation of the two stimuli in varying combinations, for 16–23 trials per *S* during the two sessions, yielded no records remotely resembling those obtained with pregnant *S*s.

Group IV.—This group consisted of two *S*s whose records indicated that the US used (noise) was ineffective before the eighth calendar month of gestation. S-5, in whom gestation had progressed to the latter part of the seventh month was exposed to 39 successive US. On only one occasion did the records show what might have been a fetal response. On eight other trials the maternal signal appeared without evidence of movement in the fetal records.

S-18 was tested at intervals from the middle of the seventh month to the middle of the eighth. During the seventh month 60 US yielded no indication of movement, either in the fetal or the maternal records. During the eighth month the US was presented four times during the first week, with the maternal signal indicating fetal movement unsupported by the direct records. In the third week, seven stimuli produced three definite fetal reactions and one indicated by the maternal signal only.

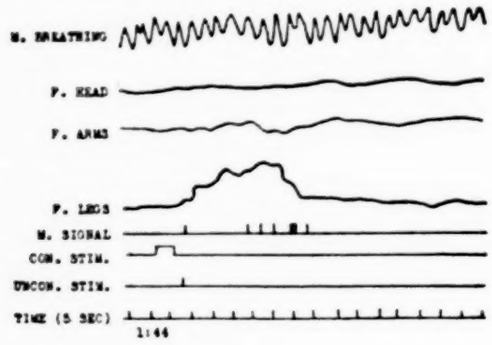

FIG. 2A

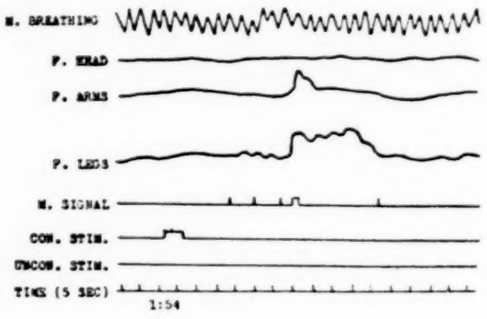

FIG. 2B

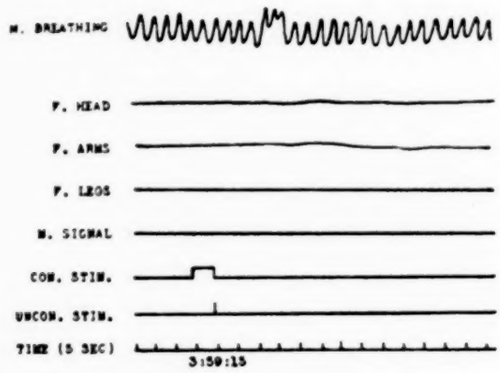

FIG. 2C

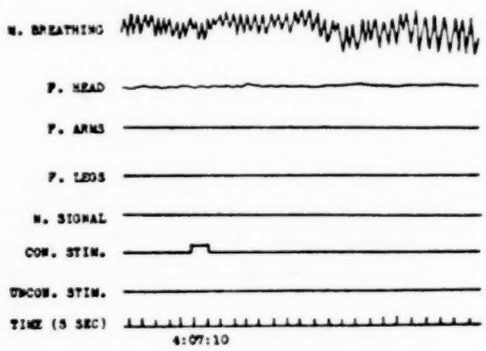

FIG. 2D

FIG. 2. Sample kymograph records from fetal conditioning study. A, showing response to both stimuli, and B, showing response to CS, obtained from same *S*. C is a record from a non-pregnant control *S*. D shows result of applying CS alone in late pregnancy without previous conditioning trials.

DISCUSSION

At present no experimental procedure will permit one to test Holt's thesis (**5**, pp. 37–43) that intra-uterine conditioning accounts for certain of the behavioral characteristics of the human neonate. On the other hand, it is clear that the human fetus can be conditioned experimentally during the last two months of pregnancy. The records, of course, cannot be expected to yield data on comparative motility of fetal head, arms, and legs. The placement of the fetal body during the last weeks of gestation and the limitations imposed by

recording only from the abdominal surface preclude such interpretation. Furthermore, it is impossible to derive precise quantitative values for latency, duration, or extent of response, for much the same reasons. Actually, examination of the records indicates that responses to paired stimuli have shorter latencies than do CRs, but the distributions overlap. In the same way, although both sharp, quick responses and slower, longer lasting movements appear, it has not been possible to attach any significance to the difference.

If these records do not permit analysis of the sort mentioned, they are, none the less, not greatly distorted by such factors as maternal breathing and gross bodily movement. When such distortion does occur, as the result of a deep sigh for example, it can be readily detected because all three fetal curves move in the same direction simultaneously, and the irregularity appears in the maternal breathing curve as well. This is never true of fetal responses, and the fact is obviously of importance in reading the curves.

The amount of agreement between the direct records and the maternal signal indicating perceived fetal movement is significant. As a measure of the degree of correspondence, a bi-serial r was computed, based upon the number of fetal curves (0–3) in which a given response appeared, and upon its presence or absence in the maternally made record. For 529 stimulations of the 13 pregnant *Ss*, $r_{bis} = .784$, $\sigma_r = .017$.

Obviously, further study of more *Ss* is to be desired. Analysis of the effective unconditioned stimuli which may be used, of the length of retention which may be obtained, and of the age at which sensitivity to auditory stimuli develops would be profitable. In this last connection, it may be significant that Langworthy (9) found fibers of the cochlear branch of the eighth cranial nerve much more lightly myelinated in a seven months fetus than in the eight months old specimen which he examined. It will be recalled that in our two *Ss* who served during the seventh month of pregnancy, the noise was almost completely ineffective as a stimulus to fetal movement. There are, then, enough problems still deserving investigation to justify further study of the fetal conditioned reaction.

Summary

Utilizing a vibrotactile CS and a loud noise as US, it was possible to establish a CR in the human fetus *in utero* during the last two months of gestation. Some 15–20 paired stimulations were required to establish the response to the point at which one could anticipate three or four successive responses to CS alone, but additional practice made possible as many as 11 successive CRs. Experi-

mental extinction, spontaneous recovery, and retention of the response over a three weeks' interval were demonstrated, as well as a significant degree of agreement between direct records of fetal movements and maternal report of perception of fetal movement.

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References

1. Brogden, W. J., & Gantt, W. H. Cerebellar conditioned reflexes. *Amer. J. Physiol.*, 1937, **119**, 277–278.
2. Denisova, M. P., & Figurin, N. L. [The problem of the first associated food reflexes in infants.] (*Vopr. Genet. Refleks. Pedol. Mladen.*, 1929, **1**, 81–88.) See: *Arch. Psychol.*, 1933, **23**, No. 148, 73–75.
3. Figurin, N. L., & Denisova, M. P. [The physiology of the differentiation of external stimuli. Based upon experimental data on the formation of differentiations in infants under one year.] (*Vopr. Genet. Refleks. Pedol. Mladen.*, 1929, **1**, 131–165.) See: *Arch. Psychol.*, 1933, **23**, No. 148, 75–76.
4. Forbes, H. S., & Forbes, H. B. Fetal sense reactions: hearing. *J. comp. Psychol.*, 1927, **7**, 353–355.
5. Holt, E. B. *Animal drive and the learning process.* New York: Holt, 1931.
6. Jones, H. E. The retention of conditioned emotional reactions in infancy. *J. genet. Psychol.*, 1930, **37**, 485–498.
7. Kantrow, R. W. An investigation of conditioned feeding responses and concomitant adaptive behavior in young infants. *Univ. Ia. Stud. Child Welf.*, 1937, **13**, No. 3.
8. Kasatkin, N. I., & Levikova, A. M. On the development of early conditioned reflexes and differentiation of auditory stimuli in infants. *J. exp. Psychol.*, 1935, **18**, 1–19.
9. Langworthy, O. R. Development of behavior patterns and myelinization of the nervous system in the human fetus and infant. *Carnegie Instn. Publ.* No. 443, 1–57.
10. Levikova, A. M., & Nevymakova, G. A. [The problem of the formation and differentiation of associated reflexes to auditory stimuli in infants.] (*Vopr. Genet. Refleks. Pedol. Mladen.*, 1929, **1**, 89–105.) See: *Arch. Psychol.*, 1933, **23**, No. 148, 77–78.
11. Light, J. S., & Gantt, W. H. Essential part of reflex arc for establishment of conditioned reflex. Formation of conditioned reflex after exclusion of motor peripheral end. *J. comp. Psychol.*, 1936, **21**, 19–36.
12. Marquis, D. G., & Hilgard, E. R. Conditioned lid responses to light in dogs after removal of the visual cortex. *J. comp. Psychol.*, 1936, **22**, 157–178.
13. Marquis, D. G., & Hilgard, E. R. Conditioned responses to light in monkeys after removal of the occipital lobes. *Brain*, 1937, **60**, 1–12.
14. Peiper, A. Sinnesempfindungen des Kindes vor seiner Geburt. *Mschr. Kinderheilk.*, 1925, **29**, 236–241.
15. Ray, W. S. A preliminary study of fetal conditioning. *Child Develpm.*, 1932, **3**, 173–177.
16. Spelt, D. K. The Manning pneumograph. *Amer. J. Psychol.*, 1939, **52**, 116.